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ABSTRACT

Investigated was the use of guided imagery as an instructional strategy for science teaching to foster the characteristics of the hypothesis generating component of scientific inquiry. The Science Curriculum Improvement Study (SCIS) and the Essence I programs were examined and evaluated to discover the extent to which each encourages the characteristics of the generation component. Recent neurophysiological and psychological data concerning information processing strategies in the brain and the Wallas model of scientific inquiry were used to conclude that hypothesis generation is performed by the right cerebral hemisphere and that in the generation of hypotheses, thinking is synthetic, imaginative, timeless, intuitive, metaphorical, and sudden. Guided imagery is concluded to be a strategy that satisfies these characteristics of the generation component and is applicable to science teaching, fostering generative thinking during the course of science inquiries. From the examination of SCIS and Essence I programs, it was concluded that, although SCIS does encourage the generating component, it does not reflect a level of awareness that translates into direct, explicit, consistent teaching methodology. The Essence I program was judged to be more effective in reflecting this level of awareness. (CS)

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AN IDENTIFICATION OF THE CHARACTERISTICS OF HYPOTHESIS GENERATION IN SCIENTIFIC INQUIRY WITH APPLICATIONS TO GUIDED IMAGERY AND TO THE SCIENCE CURRICULUM IMPROVEMENT STUDY AND ESSENCE CURRICULA

by

STANLEY EUGENE RACHELSON

A DISSERTATION

Presented in Partial Fulfillment of Requirements for the
Degree of Doctor of Philosophy in Educational
Leadership in the Department of Curriculum
and Instruction in the School of Education
Georgia State University

Atlanta, Georgia

1977

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ABSTRACT

AN IDENTIFICATION OF THE CHARACTERISTICS OF HYPOTHESIS GENERATION IN SCIENTIFIC INQUIRY WITH APPLICATIONS TO GUIDED IMAGERY AND TO THE SCIENCE CURRICULUM IMPROVEMENT STUDY AND ESSENCE CURRICULA

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Scientists in their inquiries engage in a two-component, complementary operation--hypothesis generation and hypothesis testing. Based on positions taken by science educators, it is concluded in this study that science teaching should reflect the practice of science. When a current view of science teaching is examined, however, it is found that there is an overemphasis on the testing component at the expense of the generating component. A major reason for this imbalance is that the characteristics of the testing component are already in a form (the mental operation inherent in the processes of induction and deduction) which is translated to science teaching. From this perspective, this study investigates three hypotheses.

Hypothesis One: The characteristics of the hypothesis

generating component of scientific inquiry can be identified. Two sources of information are utilized to derive the characteristics of the generation component. The first source encompasses recent neurophysiological and psychological investigations, which are concerned with the information processing strategies characteristic of each cerebral hemisphere of the human brain. The second source is an examination of the Wallas model of scientific inquiry. It possesses four stages: preparation, incubation, illumination, and verification. From these sources, it is concluded that the mental acts of the hypothesis generating component are performed by the right cerebral hemisphere of the brain. It is also concluded that these formulative acts occur during the incubation and illumination stages of scientific inquiry. When an investigator is in the process of generating plausible hypotheses relevant to a problematic situation, his/her thinking possesses these characteristics: (1) synthetic, (2) imaginative, (3) timeless, (4) intuitive, (5) metaphorical, and (6) sudden.

The second and third hypotheses, which are investigated in this study, make applications of these characteristics to the teaching of science.

Hypothesis Two: Guided imagery is an instructional strategy for science teaching which fosters the characteristics of the hypothesis generating component. Guided imagery is defined as a teaching method which leads imagery construction in a specific or general direction. The assumptions and characteristics of the strategy are examined, as well as the applicability of guided imagery to science teaching. It is concluded that this strategy satisfies the characteristics of the generation component, that it is in a form which is applicable to science teaching, and that it can be used to foster generative thinking during the course of scientific inquiries.

Hypothesis Three: The Science Curriculum Improvement Study (SCIS) and the Essence I program can be examined and evaluated to discover the extent to which each encourages the characteristics of the generation component. This investigation considers the following areas of each curriculum: (a) background and goals, (b) conceptual framework, (c) methodology, and (d) teacher's role. It is concluded that the SCIS program developers operated with the very general goal of promoting both the generating and testing components of scientific inquiry for each student. Correspondingly, this goal does not reflect a level of awareness which clearly delineates between the information processing strategies characteristic of each component of inquiry. It is also concluded that the SCIS program encourages the hypothesis generating component, but that this lack of awareness translates into a methodology and teacher's role which encourages generative thinking in an indirect, implicit, and inconsistent manner. This conclusion is evidenced with respect to each characteristic of the generation component.

The investigation of the Essence I program paralleled the examination of SCIS. The program developers of Essence I operated with the very specific goal of promoting the generating component of scientific inquiry. It is demonstrated that this goal translates into a methodology and teacher's role which encourages generative thought in a direct, explicit, and consistent manner. This encouragement was evidenced with respect to each characteristic of the generation component.

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"Sciencing Activities as Contributors to the Reading Achievement of First Grade Students", Morgan, Rachelson, and Lloyd. Accepted for publication by Science Education.
"Issues in Graduate Education", Rachelson, Finley, and Mitchell. The Georgia Science Teacher, Vol. 14, 1975.
"Exploration, Invention, and Discovery: A Science Curriculum Improvement Study Instructional Strategy". A tape-slide presentation in association with activities of the Center for Improving Elementary School Science. 10/74.
"Natural Processes - Science Education - Social Processes", Rachelson and Jaber. A paper prepared for Science Education for Man, a monograph edited by Dr. Jack Hassard, Georgia State University. 5/74.

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Science Education
Humanistic Education
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Chapter I

> We cannot in any sense be both the observers and the actors in any specific instance, or we shall fail properly to be either one or the other; yet we know that our life is built of these two modes, is part free and part inevitable, is part creation and part discipline, is part acceptance and part effort. We have no written rules that assign us to these ways; but we know that only folly and death of spirit results when we deny one or the other, when we erect one as total and absolute and make the other derivative or secondary. (Oppenheimer, 1954, p. 88)

Statement of the Problem

There are two purposes of this study. The first is to identify the characteristics of the hypothesis generating component of scientific inquiry. The second is to apply this information to an instructional strategy for science teaching and to currently used science educational curricula.

Hypotheses

There are three major hypotheses of this study. They are:

1. The characteristics of the hypothesis generating component of scientific inquiry can be identified.

2. Guided imagery is an instructional strategy for science teaching which fosters the characteristics of the generation component.
3. The Science Curriculum Improvement Study and the Essence program can be examined and evaluated to discover the extent to which each encourages the characteristics of the generation component.

Definitions

1. Scientific inquiry--the method by which science arrives at its findings (Martin, 1972). The method consists of two complementary components: hypothesis generation and hypothesis testing.
2. Complementarity--a term referring to two alternate modes of describing phenomena. Neither mode can be subsumed by the other, nor is either mode independent of the other (Blackburn, 1971).
3. Hypothesis generation--the operation, arising from a problematic situation, whereby a tentative, plausible explanation of the problem is created (Medawar, 1969).
4. Hypothesis testing--the operation of deducing logical prediction(s) from a hypothetical explanation, and inducing empirical data to correlate the prediction(s) with reality.
5. Information processing--the act(s) of analyzing and/or

synthesizing either environmental stimuli or internal sensations. Another name for thinking.

6. Consciousness--an ongoing state of information processing within the cerebral hemispheres of the human brain.
7. Information processing strategy--the characteristic method by which different kinds of information are considered by the human brain.
8. Ways of knowing--theoretical depictions of the dual and complementary nature of human consciousness.
9. Instructional strategy--a purposeful attempt to lead the learning process in a general or specific direction.

Rationale for the Study

Scientific Inquiry

Science is a process which produces an explanation of both the external, physical, and natural environment and the internal functioning of the human being. Bronowski (1965) describes this explanation as "the organization of our knowledge in such a way that it commands more of the hidden potential of nature" (p. 7). The scientific enterprise is guided by three basic assumptions about the nature of reality: (1) reality is ongoing and events occur whether man is aware of them or not; (2) reality is comprehendible and man, through intuitive insight and other means, has the ability to achieve an understanding of reality; and (3) reality displays more consistency than inconsistency, whereby observations can be repeated with similar results to produce explanations and to allow for predictions (Polanyi, 1964). Science is only one process or mode which man utilizes to achieve an understanding of reality. Other modes include religion, art, music, and poetry (Citron, 1974).

Scientific inquiry is the method by which science arrives at its findings. This method is a problem-solving operation which has two components: hypothesis generation and hypothesis testing (Martin, 1972). The term hypothesis may be defined as "an imaginative preconception of what might be true in the form of a declaration with verifiable deductive consequences" (Medawar, 1968, pp. 138-139). Although each of the components of scientific inquiry share the common ground of referring to the same reality, each component contains distinct characteristics. According to Blackburn's (1971) definition of complementarity, a complementary relationship exists between the process of generating a hypothesis and the process of testing a hypothesis. Neither operation can be viewed as independent of the other. A complete model of scientific inquiry must include descriptions of both hypothesis generation and testing.

Hypothesis generation consists of those mental activities which yield a tentative explanation of a problematic situation. A problematic situation creates an imbalance within the individual. Festinger (1962) calls this conflict "cognitive dissonance." Since there is an innate desire for the person to right imbalances and return to an equilibrium condition, the investigator, confronting a problematic situation, has an intrinsic motivation to search for an explanation to his problem (White, 1959). This explanation arises from the belief system of the individual, and is an imaginative and intuitive act. Rogers (1961) refers to the mental activities inherent in hypothesis generation as the "creative phase" of scientific inquiry and believes this operation to be subject to the personal experiences of the investigator.

For any given problematic situation, however, there are an infinite number of hypotheses which can provide an explanation for a problem. The chief function of the hypothesis generation component is to provide the investigator with only plausible hypotheses (Peirce, 1935). This is a selection process of prime importance to the scientific enterprise. A scientist may spend his lifetime engaged in testing one hypothesis and it is necessary for him to examine a hypothesis which is feasible and closely related to his problem. As Medawar (1969) writes, "the hypothesis that enters our minds will as a rule be plausible and not, as in theory could be, idiotic. But this implies some internal censorship which restricts hypotheses to those that are not absurd" (p. 53).

The "internal censorship" which Medawar refers to can be viewed as the operation by which man contacts his intuition. Intuitive acts are non-logical and may occur in scientific investigations through a variety of formats. All intuitive acts, however, have common properties which Medawar (1968) describes as "the suddenness of their origin, the wholeness of the conception they embody, and the absence of conscious premeditation" (pp. 55-56). Feyerabend (1975) refers to hypothesis generation as "discovery" and agrees with the concept that this component of scientific inquiry is non-logical, not subject to methodological rules. Intuitive acts are mental processes which reflect that portion of the mind which is closest to the operations of reality. The assumption is that man's mind evolved within the context of natural phenomena and therefore his mind is attuned to its framework. Intuition serves as a conduit between man and nature and its acts yield hypotheses that are testable with respect to the natural phenomenon in question (Poincaire, 1952; Pearce, 1973).

Once a hypothesis is generated it requires verification, through the test of experience. Bronowski (1965) believes that the act of verification distinguishes science as a mode of knowing from others, and posits that the testing of a hypothesis is the critical factor for the enormous success of the scientific enterprise.

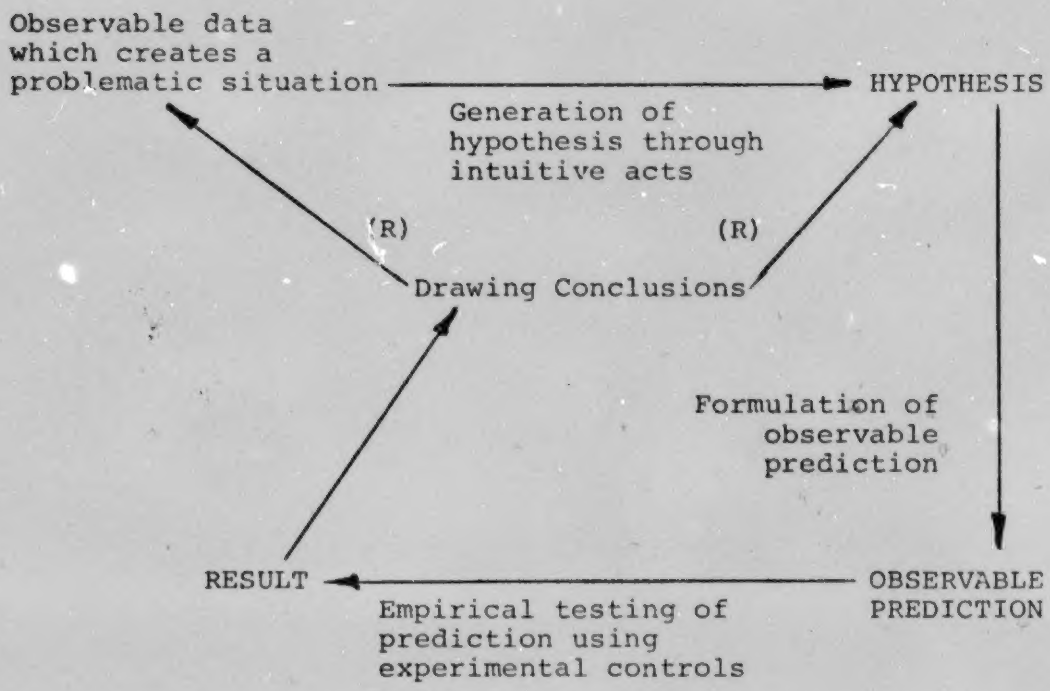
Hypothesis testing consists of those mental activities which expose a hypothesis to experience, usually by experimentation. This operation lies within and makes use of logic (Medawar, 1968). The goal of this component is to confirm or to refute the truth of a hypothesis, and is public as opposed to the private nature of hypothesis generation. Rogers (1961) views the testing operation as the "checking stage" of scientific inquiry. The investigator makes his hypothesis public to others through the use of operational definitions.

The hypothesis is tested in a manner which prevents the investigator from deceiving himself in regard to his subjectively formed hypothesis.

Hempel and Oppenheim (1948) depict this preventive manner as operating with firm rules which insure uniformity and confidence. A hypothesis exposed to criticism is analyzed by the combined use of deductive and inductive inferences. First, an observable consequence or prediction is deductively formulated. This guarantees that if the hypothesis is true, then so will be the predictions which are derived from it. Next, experimental controls are used to isolate the prediction in order to determine its correspondence with reality. If the prediction is confirmed, as defined by the testing conditions, then the hypothesis is confirmed (Hanson, 1958).

In summary, both generating and testing a hypothesis are necessary elements in the process of scientific inquiry. These operations form a complementary system of thought. Figure 1 illustrates the relationship between testing and generating a hypothesis. It presents scientific inquiry as a self-correcting, revisionary system. Herron (1971) believes this revisionary element to be critical, since it is one of the chief and unique characteristics of inquiries that are labeled "scientific."

Many individuals have offered definitions of scientific inquiry. The following definitions have been selected as representative and, while consistent with Figure 1, they


Observable data which creates a problematic situation
HYPOTHESIS
Generation of hypothesis through intuitive acts
(R)
(R)
Drawing Conclusions
Formulation of observable prediction
RESULT
OBSERVABLE PREDICTION
Empirical testing of prediction using experimental controls

(R) = Revisionary component

Figure 1. Process of Scientific Inquiry

serve to present a more varied view of the inquiry process.

Atkin (1958), in a classical study, depicts scientific inquiry as traveling through eight steps: (1) sensing a problem and deciding to find an answer for it; (2) defining the problem; (3) studying the situation for all factors bearing on the problem; (4) making the best tentative hypothesis as to the solution of the problem; (5) selecting the most likely hypothesis; (6) testing the hypothesis; (7) drawing a conclusion; and (8) making inferences based on the conclusion.

Curtis (1934), through an analysis of incidents in the history of science, reveals the following techniques characteristic of scientific inquiry: (1) locating problems; (2) making hypotheses from given facts; (3) recognizing errors and defects in condition or experiment described; (4) evaluating data or procedures; (5) evaluating conclusions in light of the facts; (6) planning and making new observations; (7) inventing check experiments; (8) isolating the experimental factor; and (9) using controls.

Keesler (1945) lists the following elements of scientific inquiry: (1) sensing a problem; (2) defining a problem; (3) studying the situation for all facts and clues bearing on the problem; (4) making the best tentative hypothesis as to the possible solution of the problem; (5) selecting the most likely hypothesis; (6) inventing and planning one or more experiments to test the hypothesis; (7) testing hypothesis by carrying out experiment; (8) running check experiments involving the same experimental factors to verify the results observed in the original experiment; (9) drawing a conclusion; and (10) making inferences based on this conclusion when facing new situations in which the same factors are operating.

Dressel, et al. (1960), in a review article, stated that the most common elements listed in the definitions of scientific inquiry include: (1) recognition of the problem; (2) collection of relevant data; (3) formulation of hypotheses; (4) testing of hypotheses; and (5) drawing conclusions.

While none of the above definitions are identical, the overall intent of the writers is the same. The intent is one of explication. This effort is necessary to the teaching of science and represents an important instructional advancement. Instructional strategies which aim to reflect inquiry must be derived from clear formulations of scientific practice.

However, when examining the elements within the definitions presented, no attempt is made to separate the hypothesis generation component from its complementary partner: hypothesis testing. Only recently has this distinction been accomplished. Medawar (1967) represents the movement to clarify the distinction between those acts which generate a hypothesis and those which test a hypothesis. He concludes, "In real life discovery and justification are almost always different processes and a sound methodology must make it clear that they are so" (p. 26).

The Teaching of Science

A National Science Teachers' Association position statement (1971) on science education states that the major goal of science teaching is the development of scientific literacy for all people. Incorporated within the concept of scientific literacy is both the understanding of key principles in science and the understanding of the nature of how scientific ideas are developed. Klopfer (1969) believes that the understanding of scientific inquiry is a more important factor than the comprehension of concepts: "A major emphasis in education for scientific literacy must be placed on the processes of scientific inquiry" (p. 88).

Recent efforts by curricula developers have been directed toward materials and strategies which facilitate the inquiry process. This energy has been interpreted as evidence of a significant change in the evolution of science teaching. There has been a shift away from the teaching just for facts and concepts (Johnson, 1969). The underlying motivation for this movement is the creation of learning environments in classrooms which are consistent with the actual practice of science. Kimbell (1968), in a survey to discover what scientists believed to be important educational outcomes for science teaching, writes: "One of the most commonly stated objectives for science education is the attainment of the understanding of the nature of science" (p. 110).

Dressel, et al. (1960), reviewed research studies which examined the effects of instructional strategies designed to encourage scientific inquiry. They found that "research studies have indicated that the acquisition of scientific methods and attitudes is facilitated by instruction" (p. 47). Given that the process of scientific inquiry can be effectively taught to students, it is necessary to examine which elements of this operation are actually being taught in science classrooms.

Quinn and George (1972) believe that: "Contemporary models for the teaching of science through inquiry place the formulation of a hypothesis high among the skills necessary for problem-solving" (p. 289). The greatest emphasis in teaching scientific inquiry, however, has been placed upon the hypothesis testing component. A review of several hundred articles dealing with research in science teaching has located only a few which examine the operations inherent in hypothesis generation. Most of the articles analyzed testing variables. (This review included an examination of articles in the Journal of Research in Science Teaching, Vols. 1-12, and articles in Science Education, Vols. 44-60.)

A representative study, Jungwirth and Dreyfus (1975), examined inquiry skills in biological investigations. All of the subjects were high school students who had completed either one or two years of the Biological Sciences Curriculum Study. The only criterion utilized to measure an understanding of inquiry was the degree to which students could design an experiment when faced with a hypothetical situation.

Clearly, this is a misrepresentation of the two-component definition of scientific inquiry and is a reflection of an overemphasis directed toward the testing stage. Ornstein (1972) believes this incomplete definition of inquiry may have originated from a cultural bias of western hemispheric persons toward rationality and away from intuition.

Furthermore, many science curricula do not give enough emphasis to the hypothesis generating component. A case in point is the Ideas and Investigating Science curriculum. The developers of IIS (1971) define scientific inquiry in the teacher's guide as a two-component operation. However, when the actual classroom activities are examined, little evidence can be found where the student is requested and allowed to intuitively generate plausible hypotheses. The real meaning of scientific inquiry fostered for the student is testing hypotheses.

For Rogers (1961), science teaching is transmitting an incomplete picture of scientific inquiry. The creative phase of formulating a hypothesis is taken for granted, is underemphasized, and tends to be forgotten. A view of science is created which is characterized by the verification of a hypothesis presented to the student. The vast structure of "operationalism, logical positivism, research design, and tests of significance" has become self-serving instead of existing "as servants in the attempt to check the subjective feelings or hunch or hypothesis of a person with objective facts" (p. 218).

Samples (1975a) attributes this trend toward hypothesis testing in the teaching of science as a reflection of a one-sided attitude toward what he refers to as "left hemispherical thinking." This attitude, identical in nature to the cultural bias referred to by Ornstein, favors the mental operations of the left cerebral hemisphere. These are the processes of logic, linearity, and time and, correspondingly, are the mental operations necessary to test a hypothesis. Samples relates this attitude as being consistent with a one-sided view of science which sees it as a totally logical and rational enterprise. This condition in science teaching is encouraged at the expense of the mental operations of the right hemisphere. These are the processes of intuition, imagery, and space and, correspondingly, are qualities of hypothesis generation.

Bruner (1963) defines the hypothesis generating component of scientific inquiry as intuitive thinking. He assumes that "intuitive thinking, the training of hunches, is a much neglected and essential feature of productive thinking not only in formal academic disciplines but also in everyday life" (pp. 13-14). Feyerabend (1975) agrees with Bruner's assessment. He criticizes science education for fostering an incomplete definition of scientific inquiry and believes that many science educators are attempting to inhibit intuition and to restrain imagination. This disposition is a serious state of affairs and Feyerabend questions "whether science can advance without strong interaction between the separated domains of justification and discovery" (p. 166). Given this condition which favors hypothesis testing, it is necessary to identify possible causes for its existence.

As alluded to previously, the teaching of science as an inquiry process is derived from explicit definitions of scientific inquiry. These definitions in turn come from the practice of science. However, the nature of hypothesis generation is private, difficult to explicate, and not subject to methodological rules. Therefore, it is quite natural that definitions of scientific inquiry are more complete with respect to the hypothesis testing component. Furthermore, hypothesis testing, a public phenomenon, lends itself to the purposes of curriculum builders in their efforts to apply definitions of scientific inquiry to instructional activities. Strategies for collecting and analyzing data and for making predictions are much easier to develop, teach, and evaluate than strategies derived from intuitive mental processes (Samples, 1975b).

Since the teaching of science is ultimately tied to a philosophical view of science, another possible cause for a disposition toward hypothesis testing lies within the origins of science. Historically, science in its developmental stages became associated with the operations involved in hypothesis testing. The establishment of science as a legitimate mode of knowing required a reactionary break with the metaphysical enterprise. Inspiration and intuition, mental acts of hypothesis generation, were viewed as too closely related to metaphysical ways of knowing. These acts became secondary to the operations of induction and deduction. Two philosophical schools of thought have propelled this reactionary view of science. They are inductivism and hypothetico-deductivism.

Hypothetico-deductivism is a more recent and refined philosophy of science. Therefore, this system is more relevant to the teaching of science than inductivism. The hypothetico-deductive philosophy, once championed by the "Vienna Circle" of logical positivists, is presently advocated by several philosophers, including Hempel, Oppenheim, Braithwaite, and Popper. This model of scientific inquiry is devoted to the reasons for accepting or refuting a hypothesis once it is well formulated. It is not concerned with the generation of a hypothesis as illustrated by Popper (1959):

> The initial stage, the act of conceiving or inventing a theory, seems to me neither to call for logical analysis nor to be susceptible of it. The question of how it happens that a new idea occurs to a man may be of great interest to empirical psychology, but is irrelevant to the logical analysis of scientific knowledge (p. 20).

Medawar (1968) proposes that the lack of emphasis placed on the hypothesis generating component of scientific inquiry by the hypothetico-deductive system is its chief weakness. He professes that "the major defect in the hypothetico-deductive scheme . . . is its disavowal of any competence to speak about the generative act in scientific inquiry . . . . The objection is all the more grave because an imaginative or inspirational process enters into all scientific reasoning" (p. 55).

Now that science is firmly established as a mode of knowing, its former reactionary underpinning can be dissolved. It is now possible to accept the fact that scientific inquiry has two equally crucial parts. Since hypothesis testing is already assumed to be a part, this acknowledgement takes the form of an identification of the characteristics inherent in the generation component. Once this analysis is complete, instructional strategies consistent with these characteristics can be developed, identified, and included in the teaching of science. Polanyi (1964) would view an emphasis on hypothesis generative acts in science teaching as an attempt to "re-equip man with the faculties which centuries of critical thought have taught him to distrust" (p. 38).

Presently, science teaching is in a state of imbalance. Students are most often presented hypotheses and are not encouraged to generate their own. Science education is placing too much emphasis on equipping students with the skills to conduct experiments, without providing enough experiences which lead to creative hypothesis formulation. In order to present a wholistic view of scientific inquiry, hypothesis generating strategies, derived from both the operations of the mind and from the practice of science, must be included, with an increased emphasis, into the planning of science education experiences for all students.

Parameters and Assumptions of the Study

In order to provide a clearer shape for this study, it is necessary to delineate and to limit the nature of several areas of discussion. These are:

1. Within the concept of hypothesis testing, two schools of thought exist: the confirmation approach and the refutation approach. No attempt is made to analyze either of these approaches.
2. When tracing the development of science, this study does not engage in a detailed analysis of either inductivism or hypothetico-deductivism.
3. This study does not examine the nature of the problematic situation. Only brief mention is made of these situations as motivators to the investigator for the hypothesis generating component.
4. This study does not examine every theoretical viewpoint about the duality of consciousness. Those that are presented are considered to be representative.
5. This study does not consider every case-study report of scientific investigations. The reports that are selected for examination are assumed to reflect the practice of science.

6. This study does not analyze all instructional strategies in view of the characteristics of the hypothesis generating component. Guided imagery is selected as representative of teaching method, which can be analyzed with respect to these qualities.
7. This study does not examine all science educational curricula for evidence of an encouragement of the generation component. Two currently used curricula are selected for discussion and are assumed to be representative.

Organization of the Study

Chapter I defines the problem and corresponding hypotheses of the study. It presents a rationale for the relevance of this investigation to the teaching of science. Chapter II is a discussion which considers the first hypothesis of the study. Six characteristics of the hypothesis generating component are identified with two kinds of evidence. The first kind is concerned with the nature of the information processing strategies of the human brain, and the second with the nature of the processes of scientific inquiry, as depicted by the Wallas model and by case-study reports of scientific investigations.

The purpose of the next two chapters is to apply these characteristics to the teaching of science. Chapter III, in making one such application, is a discussion which considers the second hypothesis of this study. It examines the guided imagery instructional strategy in relation to the qualities inherent in the generation component. Chapter IV is a discussion which considers the third hypothesis of the study. It examines two selected science educational curricula for evidence of the generation component. A systematic analysis of each curricula takes place with respect to the characteristics of hypothesis generation. Chapter V is a discussion of the conclusions that can be drawn from the information presented in this study. Included are some of the implications this information possesses for further research and teaching in science education.

Chapter II

> In all creative work I have done, what has come first is a problem, a puzzle involving discomfort. Then comes a concentrated voluntary application of great effort. After this, a period without conscious thought, and finally a solution bringing with it the complete plan of a book. (Bertrand Russell, cited in Hutchinson, 1959, p. 19)

Introduction

Chapter One has presented a two-part definition of scientific inquiry. Evidence is given to support the idea that in the teaching of science the hypothesis testing component has been overemphasized at the expense of its complementary partner--hypothesis generation. In order for science teaching to present both components of inquiry with equal emphasis, a clear explanation of the nature of hypothesis generation is necessary. It is the purpose of this chapter, in considering the first hypothesis of this study, to examine the generation component so that the explicit characteristics of this operation can be identified.

Explicating the generation component of inquiry requires three conceptual operations. First, research evidence is presented concerning the dual and complementary nature in which the human brain processes its information. This presentation is both an empirical and theoretical discussion which identifies the qualities of the thinking strategies employed by the right and left cerebral hemispheres of the brain. The second operation considers the Wallas Model of scientific inquiry, a model which is derived from the practice of science. Case study examples of scientific investigations are presented to illustrate this model. The final operation relates the stages of the Wallas Model to the generating and testing components, and this operation also relates these stages to the evidence concerning the information processing strategies of each cerebral hemisphere. It is demonstrated that hypothesis testing occurs during the verification stage of the Wallas Model, and is best performed by the strategies of the left cerebral hemisphere. Hypothesis generation occurs during the incubation and illumination stages, which are best performed by the thinking strategies characteristic of the right hemisphere. Once this examination is complete, a further synthesis of the information presented in this chapter leads to the identification of the specific mental characteristics inherent in the hypothesis generating component of scientific inquiry.

The Dual and Complementary Nature of Information Processing in the Human Brain

Empirical Support

The cerebrum is a structure of the brain which is unique to the animal kingdom. It is the most recent structure to evolve, and its functions are superimposed upon earlier brain structures. Separation of the cerebrum into two hemispheres is an even more recent evolutionary development, found only in the higher vertebrates. Studies with monkeys and other primates demonstrate that their cerebrum, while separated into two hemispheres, is not differentiated along an information processing dimension (Gazzaniga, 1970). The human brain is alone at this level of sophistication. Each cerebral hemisphere processes its information in a different manner. In this section evidence is presented to illustrate the nature of the processing strategies employed by the right and left hemispheres of the human brain.

The two hemispheres in man are connected by several bands of fibers called cerebral commissures. They provide constant communication between the hemispheres, and this interaction is almost instantaneous (within a matter of milliseconds) in the normal brain. Previous research evidence in this area did not identify the different information processing strategies employed by each of the hemispheres. This evidence was based on examinations of patients with lesion(s) in one hemisphere or the other, and in some cases, with hemispherectomy patients. It was clearly shown in these earlier studies, however, that the language and speech capability of the person resided in the left hemisphere. The right hemisphere appeared mute. A general conclusion drawn from these earlier studies was that the left hemisphere was more dominant and important than the right cerebral hemisphere (Sperry, *et al*., 1969).

The above research paradigm assumes that a loss in brain function is attributable to a particular brain damaged area. However, a major problem arises from this tradition. Goldstein (1942) has pointed out that it doesn't make sense to talk about the function of a structure that is not there. He suggests that the brain reorganizes itself in an attempt to compensate for a deficiency, and studies in aphasia illustrate this effect.

In 1962 a new research paradigm was initiated in conjunction with the study of commissurotomy patients. These patients, who were severely epileptic, had undergone an operation which severed the cerebral commissures. These commissures, the corpus callosum, the anterior commissure, and the posterior commissure, are located in Figure 2. During a severe epileptic seizure, electroencephalogram readings demonstrate that the seizure originates in one cerebral hemisphere and crosses over into the other. Previous medicative treatments did not inhibit this transfer. The purpose of the commissurotomy operation, also called the "split-brain" operation, was to contain severe epileptic seizures within their original hemisphere. This surgery has been performed on twelve individuals, and has proved effective in eliminating generalized convulsive seizures, although specific, less severe seizures still occur.

Extensive research, over a thirteen-year period, has been conducted with the split-brain patients in studying what has become known as the "disconnection syndrome." Syndrome

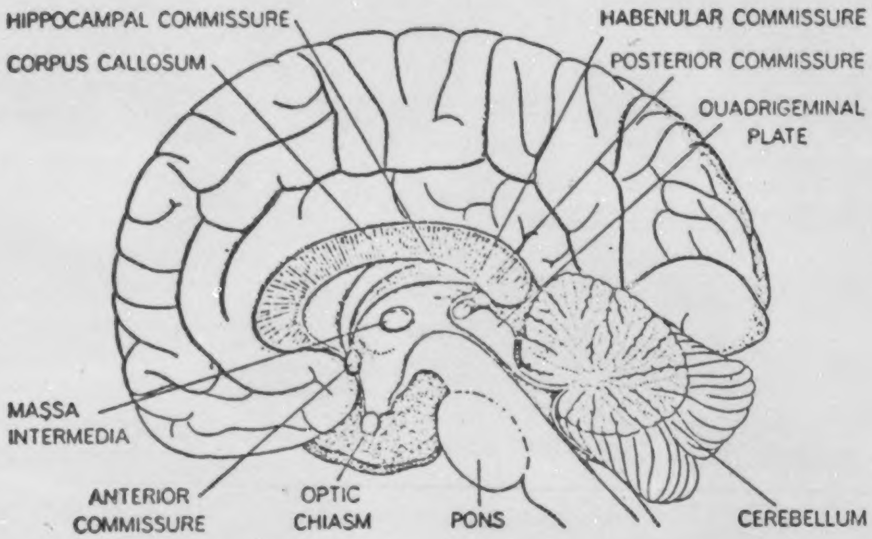

HIPPOCAMPAL COMMISSURE
CORPUS CALLOSUM
HABENULAR COMMISSURE
POSTERIOR COMMISSURE
QUADRIGEMINAL PLATE
MASSA INTERMEDIA
ANTERIOR COMMISSURE
OPTIC CHIASM
PONS
CEREBELLUM

Figure 2. Cross-section of Brain Showing One Hemisphere with Connecting Structures Cut in Split-Brain Operations. (From Sperry, 1964, p. 45)

is defined as a group of symptoms that occur together and characterize a disease. The research paradigm employed is similar to the brain-damage paradigm, since both are case study approaches. Split-brain research, however, has the distinct advantage of studying intact cerebral tissue in both hemispheres. Levy (1974) believes that previous lesion research studies, which observe behavioral outcomes of cerebral damage, are extremely difficult to interpret. Disconnection of intact areas necessitates far fewer assumptions.

Research with split-brain patients can be divided into two broad categories. The first area was concerned with the effect of cutting the connecting fibers between the left and right cerebral hemispheres. The general conclusion of this research, which results from a long series of experimental studies, is that a disconnection syndrome exists. This syndrome, displayed through many symptoms, is characterized by a functional disengagement of the right and left hemispheres with respect to nearly all cognitive activities. Learning and memory are found to proceed quite independently in each hemisphere. Information presented to one hemisphere does not cross over to the other, and integration between the hemispheres is lost. Roger Sperry, Michael Gazzaniga, and Joseph Bogen (1969), the chief researchers in this initial phase of investigation, write: "Everything we have seen so far indicates that surgery has left each of these people with two separate minds, that is with two separate spheres of consciousness" (p. 382). An important finding from this initial phase of research concerns the functioning of the right hemisphere. It was clearly demonstrated that the right hemisphere processes information with the same proficiency as the left hemisphere. The notion that the right hemisphere is minor, less functional, and unimportant when compared to the left is plainly dispelled.

Given that the two hemispheres process information separately and with equal competence after a commissurotomy, a second area of research began. This area examined the nature of this separation in order to discover whether the right and left hemisphere process their information in an identical fashion (as found with other primates), or whether each hemisphere employs different mechanisms.

Research into the nature of the information processing strategies employed by each hemisphere was conducted, as in the previous studies, by administering specific tasks to split-brain patients. In a study by Levy, Trevarthen, and Sperry (1972), three identification tasks were administered. These patients were presented with chimeric stimuli in a tachistoscopic manner (a chimeric stimulus is an image consisting of two halfs of different images joined together at the midline. The tachistoscope is an instrument that presents visual information selectively to each hemisphere.). In the first task, the subjects saw chimeric facial images. Under these conditions each cerebral hemisphere receives a different half-face to consider. The subjects were then given cardboard pictures of three different whole faces to observe, and were asked to point to the tachistoscopically presented face they had seen. This procedure was repeated for two other tasks--one which presented antler images (moose, elk, and deer), and another which presented familiar line drawings (bee, eye, and rose).

The results of each of these tasks are depicted in Table 1, and represent averages for both left and right hand response modes. These results clearly demonstrate the superiority of the right hemisphere in identifying the images presented.

In a follow-up study by Levy (1974), the same procedure was used with the same patients. This study, however, presented these subjects with words (presented chimerically and tachistoscopically) to identify instead of images. A dramatic reversal in hemispheric specialization occurred. The words presented to the right hemisphere were correctly identified on only 4% of the trials, whereas words presented to the left were correctly identified on 90% of the trials. The overall conclusion reached by Levy (1974) in these studies gives an insight into the nature of the information processing strategies of each hemisphere.

> Each side of the brain is able to perform and choose to perform a certain set of cognitive tasks which the other side finds difficult or distasteful or both. In considering the nature of the two sets of functions, it appears that they may be logically incompatible. The right hemisphere synthesizes over space. The left hemisphere analyzes over time. The right hemisphere notes visual similarities to the exclusion of conceptual similarities.

Table 1

Visual Imagery Identification by Commissurotomy Patients*

Task	Right Hemisphere Correct Responses	Left Hemisphere Correct Responses
Faces	77%	15%
Antlers	75%	15%
Line Drawings	94%	5%

* These results do not include the error rate.

> The left hemisphere does the opposite. The right hemisphere perceives form, the left hemisphere detail. The right hemisphere codes sensory input in terms of images, the left in terms of linguistic descriptions. (p. 167)

Other empirical studies, by Seamon and Gazzaniga (1973) and Bower (1970), have confirmed the cerebral lateralization described by Levy. Table 2 illustrates the different characteristics of the information processing strategies employed by each cerebral hemisphere.

When examining the different strategies utilized by each hemisphere, it is discovered that the operations of the right and left hemisphere complement each other. Levy (1974) believes that it is as if one hemisphere simply does not bother to process information which can be more adequately handled by the other. During a reading task, for example, the left hemisphere is superior in its performance when compared to the performance of the right. Reading is a skill which requires a linear and elemental processing strategy. During a visual-spatial task, such as perceiving three-dimensional shapes, the right hemisphere is superior in its performance when compared to the performance of the left. This task requires a wholistic, diffuse type of information processing strategy.

In order to apply research with commissurotomy patients ultimately to the identification of the characteristics of the hypothesis generation component, it is necessary to relate these findings to individuals with intact cerebral

Table 2

Information Processing Strategies of the Cerebral Hemispheres

Left Hemisphere	Right Hemisphere
Analytical (Rational)	Synthetic (Wholistic)
Time (Linear)	Space (Timeless)
Verbal	Images
Detail (Sequential)	Form (Diffuse)

commissures. Sperry (1968) writes that while split-brain patients lead normal lives, and the disconnection syndrome is only observed under controlled conditions, it is misleading to assume that these patients are more mentally stable without connected commissures. Zaidel and Sperry (1974) have demonstrated a significant memory impairment after commissurotomy. They concluded that the inter-hemispheric commissures are important to memory, especially in the initial encoding of perceived information and at later stages in the retrieval of engrams formed in each hemisphere. A critical implication of this research indicates that most environmental events encountered by a person require both left and right hemispheric functions.

Kimura (1973) administered a variety of tasks to normal subjects in order to confirm hemispheric differentiation within individuals with intact cerebral commissures. Information was presented to the subjects along auditory and visual modes, using a sophisticated methodology. Auditory tasks included identifying words, nonsense syllables, and backward speech. Information was presented in a dichotic listening manner. The visual tasks included identifying letters, words, two-dimensional point locations, matching of slanted lines and a task on stereoscopic depth perception. Information was presented for 100 milliseconds in a tachistoscopic manner.

Results of these tasks indicated left hemispheric superiority in identifying words, nonsense syllables, and backward speech and letters. The right hemisphere was found superior in identifying a melodic pattern, two-dimensional point locations, matching of slanted lines, and on stereoscopic depth perception. This evidence is consistent with the split-brain research and supports the concept that each hemisphere employs a different information processing strategy. Identifying words, letters, and nonsense syllables requires an analytic and linear processing strategy, whereas identifying melodic patterns and spatial locations requires a synthetic and Gestalt processing strategy.

The research by Kimura (1973) also supports the position taken by Joseph Bogen (1973) when he posed the interesting question: Does cerebral commissurotomy produce a splitting or doubling of the mind, or is it more correctly considered a maneuver making possible the demonstration of a duality previously present? Bogen believes that a duality does exist and that it may be the essential function of the commissures to synchronize the hemispheres so that an integrated singular mind confronts environmental events.

This duality hypothesis was fostered originally by Hughlings Jackson in the 19th Century. He stated, in 1864, that: "If then it should be proved by wider evidence that the faculty of expression resides in one hemisphere, there is no absurdity in raising the question as to whether perception, its corresponding opposite, may not be seated in the other" (Taylor, 1958, p. 220). As previously mentioned, brain lesion research did demonstrate that the faculty of expression resides in the left hemisphere. Split-brain research and

Kimura's work confirmed this, but more importantly, these studies showed that visual-spatial perception was best performed by the right hemisphere. In addition, a critical factor in the rise of the duality hypothesis is the removal of the assumption that the right hemisphere is minor with respect to the left. Present data indicate that the left and right cerebral hemispheres share equal responsibility for information processing. It is now believed that the human brain operates through the integration of two complementary modes of consciousness. The mechanisms in which the hemispheres interact with each other is not clearly understood. Ornstein (1972) believes that in most activities the person simply alternates between the right and left hemispheres, selecting the appropriate one and inhibiting the other.

Theoretical Evidence

Bogen (1973), in expanding the functions of each cerebral hemisphere from their research base, took the creative step of connecting two different frames of reference: the empirical frame, which describes the dual and complementary nature of information processing within the cerebral hemispheres; and the theoretical frame, which describes the dual and complementary nature of human consciousness. The idea that human consciousness has a dual and complementary nature has been a part of human awareness for many centuries, and has transcended cultural boundaries. For example, around the year 3,000 B.C. the Chinese, in developing the I Ching, described the dual nature of consciousness as composed of a Yin and a Yang component.

The underlying assumption for developing a theory of duality and complementarity of consciousness is that the human mind has evolved within a universal framework which is also bimodal in nature. Some common examples include: night-day, electro positive-electro negative, black-white, male-female. Joseph Pearce (1973), in his examination of the relationship between man and reality, states that: "man's mind is a mirror of the universe that mirrors man's mind, though the mirroring is subtle, random and unfathomable" (p. 85). In relation to the duality hypothesis postulated by Bogen (1973) and Jackson (1864), many researchers and theorists acknowledge the dichotomies of the two modes of consciousness. Table 3 is a compilation of several dichotomies without reference to specific hemispheres.

Jerome Bruner (1963) speaks of two complementary ways of knowing: intuitive thinking and analytic thinking. Intuitive thinking "characteristically does not advance in careful, well-defined steps. Indeed, it tends to involve maneuvers based seemingly on an implicit perception of the total problem" (p. 58). The individual operating along this way of knowing is unaware of his information processing strategy. It is the intuitive mode which yields a hypothesis which is formulated through the immediate apprehension of the meaning, significance, or structure of a problematic situation.

Analytic thinking, in contrast, characteristically

Table 3

Dual and Complementary Nature of Consciousness

Suggested By	Dichotomies	
Jerome Bruner (1963)	Analytic Thinking	Intuitive Thinking
Abraham Maslow (1966)	Abstract	Experiential
Henri Poincaire (1952)	Conscious Ego	Subliminal Ego
Robert Samples (1975)	Rational Mind	Metaphoric Mind
Arthur Koestler (1964)	Straight Thinking	Thinking Aside
Michael Polanyi (1964)	Explicit	Tacit
Robert Pirsig (1974)	Classical	Romantic
Thomas Blackburn (1971)	Intellectual	Sensuous
Robert Ornstein (1972)	Rational-Western	Intuitive-Eastern
Joseph Bogen (1973)	Propositional	Appropositional

proceeds a step at a time. These steps are "explicit and usually can be adequately reported by the thinker to another individual" (Bruner, 1963, p. 57). The person operating primarily along this mode of consciousness may be involved in deductive reasoning, relying on mathematics and logic, and he/she may be involved in a sequential process of induction and experiment utilizing the principles of research design and statistical analysis.

Abraham Maslow (1966) refers to two kinds of knowing which are complementary to each other. Experiential knowing is "timeless, placeless, societyless, historyless" (p. 53). The person operating in this manner is not filtering his experience through any a priori ideas of what the experience should be. There is a disappearance of criticism, editing selection, and evaluation. Maslow describes the experiential mode of knowing as "laying aside all the characteristics of our most prideful rationality, our words, our analysis, our ability to dissect, to classify, to define, to be logical" (p. 54).

Abstract knowing involves the ordering and analysis of experience. The person operating primarily within this mode is filtering his experience in order to organize them for understanding. Maslow describes the abstract mode as the "holistic hierarchizing of experience" (p. 67).

Henri Poincaire (1952), in describing the process of discovering and verifying the hidden harmonies and relations of mathematical order, outlines a procedure which alternates between the two modes of consciousness. He refers to this procedure as the "working of the two egos" (p. 63). The subliminal ego controls the thought processes which create combinations of mathematical order. Poincaire states that the rules which guide the subliminal ego are "extremely subtle and delicate and it is practically impossible to state them in precise language; they must be felt rather than formulated" (p. 57). It is the chief responsibility of the subliminal mode of knowing to present to its complementary partner, the conscious ego, fruitful mathematical combinations which are highly probable and relevant to the nature of the problem under consideration. The conscious ego takes the hypothesis generated by the subliminal ego and attempts to verify it. Poincaire describes the rules of operation of the conscious ego as "strict and complicated; they demand discipline, attention, will and consequently consciousness" (p. 63). Poincaire's term "consciousness" refers to his belief that the individual is fully aware of the work of the conscious ego; whereas he is only partially aware of the subliminal ego. This idea is consistent with the evidence of the split-brain research. The right hemisphere without a sophisticated language capability appears mute, and its processing of information could be interpreted as something the individual is only partially aware of when compared to the left hemispheric processing.

A Synthesis

When synthesizing the characteristics of these duality theories, two important relationships emerge. First, the terms each of the theorists uses to describe the dual and complementary nature of consciousness are intimately related to each other. The terms: intuitive thinking, experiential, subliminal ego, metaphoric mind, thinking aside, romantic, tacit, sensuous, intuitive, and appropositional have common qualities, as do the terms: analytic thinking, abstract, conscious ego, rational mind, straight thinking, classical, explicit, intellectual, rational, and propositional.

Maslow's description of "experiential knowledge" as timeless, placeless, and without the filter of prior experience is similar to the processes of the "subliminal ego" as a place "where there reigns liberty, if one could give this name to the mere absence of discipline" (Poincaire, 1952, p. 63). Also, "intuitive thinking," in Brunerian terms, is similar to both "experiential knowledge" and the "subliminal ego" because it does not proceed in well-defined steps. In addition, the "subliminal ego," as a process that must be felt rather than formulated, is correlated to Bruner's characterization of "intuitive thinking" as a way of knowing which occurs without the individual's awareness of its process.

Maslow's portrayal of "abstract knowing" as a rational organization of experience is quite similar to Poincaire's idea of the "conscious ego," which is disciplined and orderly. Bruner's term "analytic thinking" is also intimately related to the terms "abstract knowing" and "conscious ego," since this thinking proceeds in an orderly, organized, and sequential fashion. Both Bruner and Maslow use the word "logical" in depicting "analytic thinking" and "abstract thinking" respectively.

The second relationship which emerges in this synthesis involves the qualities of the empirical terms in Table 2 and those of the theoretical terms in Table 3. Bogen (1973) and Ornstein (1972) allude to a direct link between the theoretical dichotomies of consciousness and the characteristics of the processing strategies of each hemisphere. A comparison between these tables supports their contention, and is presented in Table 4.

Upon examination it is apparent that the theoretical descriptions of human consciousness (or ways of knowing) on the right side of Table 4 are functions of the right cerebral hemisphere, and those on the left side are functions of the left hemisphere. For example, Maslow (1966), in portraying "experiential knowledge," uses the terms: "timeless" and "historyless." These terms are closely related to the experimental split-brain terms, diffuse and timelessness, since history and time are linear and sequential processes. Poincaire (1952) and Bruner (1963) speak of the individual as not being fully aware of the operations of the "subliminal ego" and of intuition respectively. This idea correlates to the non-verbal nature of the information processing strategy employed by the right cerebral hemisphere. Furthermore,

Table 4

The Relationship Between the Empirical and Theoretical Depictions of Human Consciousness

	Left Hemisphere	Right Hemisphere
Empirical Support	Analytical (Rational)	Synthetic (Wholistic)
	Time (Linear)	Space (Timelessness)
	Verbal	Images (Non-Verbal)
	Discrete (Sequential)	Form (Diffuse)
Theoretical Support	Analytical Thinking	Intuitive Thinking
	Abstract	Experiential
	Conscious Ego	Subliminal Ego
	Rational Mind	Metaphoric Mind
	Straight Thinking	Thinking Aside
	Explicit	Tacit
	Classical	Romantic
	Intellectual	Sensuous
	Rational-Western	Intuitive-Eastern
	Propositional	Appropositional

Bruner posits that the person who thinks intuitively will implicitly perceive the total problem confronting him. Correspondingly, split-brain research reports that patients, when given information only to the right hemisphere, perceive it in a wholistic and synthetic manner.

"Abstract knowing" follows an organized pattern and the "conscious ego" is guided by strict rules. Both of these modes of consciousness are correlated with the left hemisphere's discrete and linear strategy. Bruner's description of the term "analytic thinking" directly corresponds with experimental results which demonstrate the analytic nature of the left hemispheric information processing. Poincaire and Bruner both agree that the operations of the "conscious ego" and "analytic thinking" respectively can be reported to another person. This view is consistent with verbal mediation which is characteristic of the processes of the left cerebral hemisphere.

Samples (1976) is very explicit in making a direct link between the cerebral hemispheres and his two modes of consciousness: the metaphoric mind and the rational mind. He states that "the right cerebral hemisphere in most people is the residence of the metaphoric mind" (p. 19). Correspondingly, the left hemisphere houses the rational mind. Furthermore, these two modes have qualities which are consistent with the previously mentioned theoretical frameworks depicted by Bruner, Maslow, and Poincaire.

The metaphoric mind is characterized as an intuitive, inventive, wholistic, and imaginative. "The metaphoric mind treats all input as fragments of reality, and as soon as a fragment appears the mind begins to search for the whole" (Samples, 1976, p. 18). In this search this mode operates by finding _metaphoric_ relationships between two previously distant objects or events. "This mind gathers valid linearities and casts them into cyclic metaphoric thinking to seek out where they belong. They tumble and churn and, like magnets tossed into a whirlpool, gradually form patterns of meaning. If these patterns are valid, they are retained" (Samples, 1976, p. 98).

It is the function of the rational mind to formulate the initial valid linearities which are cast together, as well as to determine the validity of a new metaphorical relationship. The rational mind accomplishes this operation through logical thought processes. These processes are characterized as linear and verbal. This mode of consciousness, Samples (1976) says, "strings things together sequentially in language and in linear time sequences . . . . It sees things discretely and its processes tend to converge toward the single most logical outcome in a series of thoughts" (p. 18).

Recent neurophysiological research evidence and several theoretical viewpoints present a picture of man who functions through an interaction of two distinct modes of knowing. These modes are complementary to each other. Left hemispheric operations cannot be subsumed by right hemispheric operations and vice versa. A complete description of an individual who is solving problems, which arise from environmental confrontations, includes both left and right hemispheric operations. As stated in the rationale section of Chapter One, scientific inquiry is a two-component problem-solving process, and that these components interact in a complementary manner. Thus far, the theoretical depictions of Bruner, Poincaire, and Samples have alluded to this two-component definition of inquiry. It appears that the generation component may reside in the right cerebral hemisphere, whereas the testing component may be housed in the left hemisphere. For further support of this contention, it is necessary to examine a model of scientific inquiry and case-study reports of scientific investigations.

The Wallas Model of Scientific Inquiry

Graham Wallas (1927) presents a model of scientific inquiry which moves through four stages: preparation, incubation, illumination, and verification. Wallas relied upon many descriptions of mathematical and scientific investigations in order to create his model. Those inquiries of particular significance came from the German physicist, Herman von Helmholtz, and from the French mathematician, Henri Poincaire.

Preparation

The preparation stage begins after the scientist is confronted with a problematic situation. This stage consists of a "hard, conscious, systematic and fruitless analysis of the problem" (Wallas, 1927, p. 81). The mental processes of deduction and induction operate during the preparation stage. These logical inferences can be characterized as systematic, linear, and analytic. Logic is the study of the strength of arguments and logical inferences are statements that form an evidential link between premises and conclusions of arguments (Skyrms, 1966).

Deductive arguments are most often derived from laws or principles which are known to be true in all cases.

> All objects which burn require oxygen.
> Candle X is an object which will burn.
> Candle X requires oxygen.

The nature of deductive arguments is such that if the major premise is true (All objects which burn require oxygen), then so is the conclusion (Candle X requires oxygen). The quality of a deductive argument is depicted as either valid or invalid. The criterion for judging these arguments is the probable truth value of the major premise.

Inductive arguments are most often derived from fewer observations than deductive arguments and do not possess the same level of certainty. The following is an example of an inductive argument:

> There have been 16 cases where a candle is placed into a container with water in it (at a level of no more than ¼ of its length), lighted and covered with another container.
>
> When the candle was lit and covered in each case, the candle eventually went out

> and there was a subsequent rise in the water level.
>
> All candles placed in a container with water in it (at a level of no more than ¼ of its length) that are lighted and covered with another container will eventually go out and there will occur a subsequent rise in the water level.

The standards which are used to evaluate the nature of inductive arguments differ with those used to judge deductive arguments. The quality of an inductive argument is based on the probability that its conclusion is true given the premise and is characterized as either strong or weak. The above example can be judged to be an inductively strong argument. It could be transformed into an even stronger argument by increasing the number of cases in the major premise from 16 to 200 (Skyrms, 1966).

By relating the above discussion concerning deductive and inductive inferences to the information processing evidence as presented in the previous section, an interesting correspondence emerges. The characteristic operations of the left cerebral hemisphere, as determined by neurophysiological studies and by theoretical depictions of consciousness (Table 4), are consistent with the mental processes inherent in both deductive and inductive inferences. The left hemisphere processes its information in a linear, analytical, and discrete manner. This strategy is required when deriving a conclusion statement from a major premise. Also, Ornstein's (1972) characterization of left-hemispheric operations as rational and Bogen's (1973) depiction of these mental acts as propositional closely match the nature of the operations of deduction and induction. It can be concluded that the information processing strategies employed by the investigator during the preparation stage is best performed by the left cerebral hemisphere.

Arthur Koestler (1967), in an examination of creative acts, would classify the mental strategies of the preparation stage as operations which lie within one frame of reference or matrix. The investigator relies upon immediately associated concepts and habitual thought patterns (described by Koestler as "straight thinking") to keep the problem within this single frame of reference. After a fruitless analysis of the problem, the hypothesis under consideration is not confirmed. A stressful or blocked condition results leading to the creation of motivational energy which is identical in nature to the energy created when the initial problem confronted the investigator. This energy, however, becomes channeled into a different direction than the energy aroused by the initial conflict which led to the implementation of logical inferences. As Koestler writes, "when a situation is blocked, straight thinking must be superceded by 'thinking aside'--the search for a new auxiliary matrix which will unblock it, without having ever before been called on to perform such a task" (p. 163). "Thinking aside" refers to thinking intuitively which, as previously mentioned, does not proceed in a logical or linear fashion. The incubation stage of scientific inquiry is the place where "thinking aside" in search for a new matrix occurs.

Incubation

Wallas (1927) describes the incubation stage as a voluntary abstention from conscious thought. Conscious thought is defined as an intentional and purposeful attempt to solve a problem. Historical accounts of scientific investigations illustrate a wide variety of incubation formats. A. R. Wallace, a discoverer of the theory of evolution by natural selection, incubated during intermittent attacks of malarial fever; August Kekule, discoverer of the configuration of the benzene ring, incubated in the form of dream images; Henri Poincaire incubated during a sleepless night caused by drinking several cups of strong coffee; and Hermann von Helmholtz would characteristically incubate during long walks after dinner.

Whatever the format employed as an abstention from conscious work on a problem, the underlying goal of the incubation stage is the same. It is the search for a successful frame of reference from which the current problem can be viewed. According to Koestler (1967) and Poincaire (1952), there are an infinite number of reference frames from which a problem can be viewed. During incubatory thought these frames are sifted and reshuffled in order to select the one which can successfully interact with the reference frame analyzed during the preparation stage. Samples (1976) would describe this interaction as a metaphorical connection. This characterization of the incubation stage is quite similar to an earlier description by Medawar (1969) of the hypothesis generating component, where intuitive thought processes select only plausible hypotheses from an infinite number of possibilities.

A revealing portrayal of the interaction between the preparation and incubation stages is conveyed in Poincaire's (1952) "hooked atom" analogy. He visualized all concepts as groups of atoms hooked together and attached to a wall (Koestler would call these groups different frames of reference). It is interesting to note that Shavelson (1974), in his description of cognitive structure of memory, views a concept as a group of ideas hooked together in a fashion similar to Poincaire's description. Figure 3 is an example of Shavelson's image of a conceptual framework, which is stored in a person's memory. The lines between each idea represent the various relationships between ideas. Also, there may be any number of lines connecting two or more ideas.

During the preparation stage, as depicted by Poincaire (1952), the "hooked atoms" remain fixed to the wall, since the conscious ego is dominating the individual's activity. Poincaire would probably say that it is the work of this stage to build up the necessary tension that causes the release of groups of "hooked atoms." Koestler (1964) would refer to this release as being caused by the stress aroused by the fruitless analysis of the problem within one reference frame. As incubation begins and voluntary abstention from the problem occurs, Poincaire writes that, "some of them [groups of hooked atoms] are detached from the wall and set in motion. They plow through space in all directions . . . like the

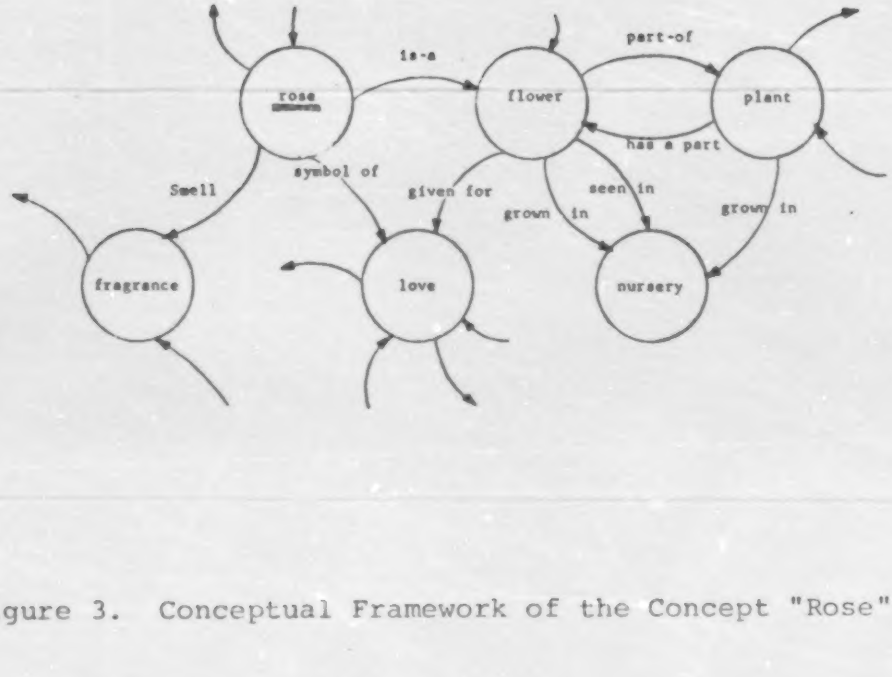

rose
is-a
flower
part-of
plant
has a part
Smell
symbol of
given for
seen in
grown in
grown in
fragrance
love
nursery

Figure 3. Conceptual Framework of the Concept "Rose"

gaseous molecules in the Kinetic Theory of Gases. Their mutual collisions may produce new combinations" (p. 61). The movement is guided by the intuitive thought processes of the subliminal ego. Chance and wasted collisions do not occur, but those that are productive in solving the problem do. This guidance is the process of "internal censorship" referred to by Medawar (1969) in his definition of the hypothesis generating component.

Before two independent frames of reference (two groups of "hooked atoms") are brought together, a dual selection process occurs. First, the preparation stage of inquiry determines the release of only some of the infinite number of "hooked atom" groups. Second, the incubation stage guides these liberated groups in an unordered and non-analytic manner. At the point of combination between the preparatory frame and the incubatory frame, illumination occurs. This synthesis is in the form of a plausible hypothesis which provides an explanation of the problem under consideration.

A representative example of the incubatory experience in a scientific inquiry comes from the investigations of the naturalist, Alfred Russell Wallace. Wallace (1905) had been working on a theory to explain the origin and variety of all living organisms. He had traveled great distances on many expeditions in search for this explanation. The preparation stage of his inquiry took place during these expeditions and during the time he spent in England between them. Wallace had amassed huge amounts of data concerning the distribution of many species of life. In a letter to Henry Bates in which he related the findings of an expedition to the Andes, Wallace listed the following insects he had collected:

Butterflies	620 species
Moths	2000 species
Beetles	3700 species
Bees, Wasps, etc	750 species
Flies	660 species
Bugs, Cicadas, etc	500 species
Locusts, etc	160 species
Dragon flies	110 species
Ear Wigs, etc	40 species
Total	8540 Species of Insects

(p. 360)

The problematic situation guiding Wallace's (1905) inquiry during this long period of preparation was that the great mass of facts about the distribution of organisms "had never been properly utilized as indications of the way in which species had come into existence" (p. 354). His analysis of the problem, in an essay entitled, "On the Law Which Has Regulated the Introduction of New Species," led to the hypothesis that "every species has come into existence coincident both in space and time with a pre-existing closely allied species" (p. 355). Wallace confirmed this hypothesis which provided an explanation of the problem of *when* and *where* species originated, but it left him without an explanation as to how various species of life came into being. At this time, "straight thinking," left hemispheric analysis did not produce an answer to this problem. An incubation period in search for a new matrix ensued.

Wallace continued his travels; this time he went to the Malay Archipelago. He had contracted malaria on a previous expedition and was seized by attacks of intermittent fever which required him to rest for several hours during each attack. Wallace (1905) describes these attacks as periods "during which time I had nothing to do but to think over any subject then particularly interesting me" (p. 361). As described earlier, the incubation stage is a period of voluntary abstention from conscious thought, whereby intuitive thinking can occur. It is assumed that an attack of malarial fever, which gave Wallace this freedom, facilitated such an abstention from conscious thought. A new auxiliary matrix (Malthus' principle of population) came to Wallace during one of his attacks and was responsible for unblocking the problem of how species originated.

Wallace (1905) describes this experience in his autobiography:

> One day something brought to recollection Malthus' "Principles of Population," which I had read about twelve years before. I had thought of his clear exposition of the "positive checks to increase"--disease, accidents, war, and famine--which keep down the population of savage races to so much lower an average than that of more civilized peoples.
>
> It then occurred to me that these causes or their equivalents are continually acting in

> the case of animals also . . . . Vaguely thinking over the enormous and constant destruction which this implied, it occurred to me to ask the question, Why do some die and some live? And the answer was clearly, that on the whole the best fitted live . . . . Then it suddenly flashed upon me that this self-acting process would necessarily *improve the race*, because in every generation the inferior would inevitably be killed off and the superior would remain--that is, *the fittest would survive*. Then at once I seemed to see the whole effect of this, that when changes of land and sea, or of climate, or of food supply, or of enemies occurred--and we know that such changes have always been taking place--and considering the amount of individual variation that my experience as a collector had shown me to exist, then it followed that all the changes necessary for the adaptation of species to changing conditions would be brought about; and as great changes in the environment are always slow, there would be ample time for the change to be effected by the survival of the best fitted in every generation. In this way every part of animal's organization could be modified exactly as required, and in the very process of this modification the unmodified would die out, and thus the *definite* characters and the clear *isolation* of each new species would be explained. The more I thought over it the more I became convinced that I had at length found the long-sought-for law of nature that solved the problem of the origin of the species . . . . I waited anxiously for the termination of my fit so that I might at once make notes for a paper on the subject. The same evening I did this pretty fully, and on the two succeeding evenings wrote it out carefully in order to send it to Darwin by the next post" (pp. 361-363).

In expounding upon the above description of the incubation stage, it will be necessary to apply Wallace's account to the conceptual framework of this study. Wallace begins by saying "something brought to recollection Malthus' 'Principles of Population'." It is evident from Wallace's writings on the subject of evolution that an imbalance occurred in his thinking after the preparation stage hypothesis did not explain how various living organisms came into being. This conflict created the motivational energy which powered his incubation. The phrase "something brought" is an action concept which can be implied to signify this desire or motivation.

These words, "something brought," also indicate that Wallace, given his feverish state, was neither completely aware of how the ideas of Malthus came to him nor where they came from. This lack of conscious awareness is consistent with one of the previously mentioned properties of intuitive acts. In addition, Wallace uses the phrase "vaguely thinking" to describe his thought processes during his attack. This phrase is highly correlated to Poincaire's description of the operation of the "subliminal ego," which are guided by rules that are subtle and difficult to state in precise language and it is also consistent with the non-verbal, diffuse nature of the right hemisphere.

It is most significant that the Malthus frame of reference was brought to Wallace's attention and not, as could be, an infinite number of other matrices. Since Wallace had been engaged in a logical analysis (straight thinking) of the problem of how species originated (in the preparation stage), it is evident that one selection process had occurred. If the term "something" is translated to mean "intuitive insight," the beginning phrase of the Wallace account would read: "One day an intuitive insight brought to recollection Malthus' 'Principles of Population' . . . ." From this phrase one can infer that a second selection process occurred. Because man's mind evolved within the context of all natural phenomena and is attuned to its structure, Wallace's thinking, guided by the subliminal ego, selected a successful frame of reference from which his problem could be viewed.

Wallace brought together two distinctive frames of reference: a sociological construct concerning population parameters of humans and a biological matrix dealing with the origin of all species of life. This combinatory act suggests that a wholistic information processing strategy was employed. This strategy is synthetic in nature as opposed to the step-by-step logical analysis required during the preparation stage of scientific inquiry, and it is consistent with the operations of the right hemisphere. Wallace states that he had read Malthus' writings twelve years prior to his fever attack. This statement is again compatible with the unordered, diffuse, and timeless nature of right hemispheric strategies.

Wallace describes his insight by the phrases: "sudden flash" and "then at once I seemed to see the whole effect of this . . . ." These depictions are uniformly related to one of the properties of intuitive acts--the suddenness of their origin. At the point of synthesis, the two reference frames are combined and the incubation stage fades into the illumination stage of scientific inquiry.

Historically, it is interesting to note that Darwin had arrived at the same hypothesis of natural selection only a few years earlier. Although Darwin incubated in a different format he, too, combined Malthusian principles with biological concepts. This similarity in hypothesis formation can be viewed as pure coincidence, but Pearce (1973) makes a strong argument that intuitive insights are as universal and timeless as the truths of reality they express. The theory of evolution by natural selection had enormous ramifications on how man views himself. Bronowski (1973) writes that "The theory of evolution by natural selection was certainly the most important single scientific innovation of the Nineteenth Century . . . . The living world was different because it was seen to be a world of movement. The creation is not static but changes in time in a way that the physical processes do not" (p. 308-309).

Illumination

The illumination stage of inquiry is intimately related to the incubation stage, and sharp lines of demarcation between them do not exist. The reference frame arrived through incubation is a right hemispheric product and is non-verbal and imaginary in nature. At the point of illumination this frame becomes verbalized suddenly to the individual and completion of the interaction between the preparatory and incubatory matrices occurs. The gap between the hemispheres is bridged during this stage.

Case-study evidence indicates that illumination is a brief and highly energetic stage. The individual is usually overcome with a flood of emotion which stops his activity and causes immediate reflection. Koestler (1964) and Pearce (1973) have referred to this stage as the "Eureka experience." Pearce states that "In every recorded case of Eureka! illumination, the final breakthrough of the postulate occurs at a moment when the logical processes have been momentarily suspended . . ." (p. 72).

One fascinating illustration of the incubation and illumination happened to August Kekule, who was investigating the molecular structure of various organic compounds. The preparation stage had led to a fruitless analysis of the known frame of reference--the current conception of the atomic configurations of organic compounds. The following is an excerpt of a speech in which Kekule describes his incubatory dreams and subsequent illumination. Shortly thereafter his benzene ring hypothesis was tested and verified.

> It was very much the same with the Benzene Theory. During my stay in Ghent, Belgium, I occupied pleasant bachelor quarters in the main street . . . . I was sitting there engaged in writing my textbook; but it wasn't going very well; my mind was on other things. Again the atoms were flitting before my eyes. Smaller groups now kept modestly in the background. My mind's eye, sharpened by repeated visions of a similar sort, now distinguished all. in movement, winding and turning like serpents! And see! What was that? One of the serpents seized its own tail and the form whirled mockingly before my eyes. I came awake like a flash of lightning. This time also I spent the remainder of the night working out the consequences of the

> hypothesis. If we learn to dream, gentlemen, then we shall perhaps find the truth-- . . . . . we must take care, however, not to publish our dreams before submitting them to proof by the waking mind. (Libby, 1922, p. 269)

This case study of hypothesis generation is consistent with several characteristics of right-hemispheric thinking. Kekule made the metaphorical connection between a serpent biting his tail and the ring structure of organic molecules. This connection occurred in the form of dream images. Koestler (1964) refers to this image as one of the most brilliant examples of hypothesis generation to be found in the whole range of modern chemistry, and one of the cornerstones of modern science.

Thus far, scientific inquiry has been presented, via the Wallas model, as a process which proceeds from a problematic situation and a fruitless analysis to the generation of a plausible hypothesis through the stages of incubation and illumination. The left and right hemispheres have both assumed the role of orchestra leader. The left for the preparation stage and the right for the incubation, with both hemispheres co-leading the brief, climactic illumination stage. The final stage of the Wallas model is verification.

Verification

The verification stage closely resembles the preparation stage, since the same rules of logical inference apply to both. Predictions are deduced from the plausible hypothesis and experimental conditions are induced to test these predictions. Poincaire (1952) calls the verification stage a "second period of conscious work which follows the inspiration, and in which the results of the inspiration are verified and the consequences are deduced" (p. 63). This stage is the hypothesis testing component of scientific inquiry. When the knowledge of how information is processed in the human brain is related to the verification stage, it is evident that this operation, as in the preparation stage, is best performed by the strategies of the left cerebral hemisphere.

In reflecting upon the above model for scientific inquiry, it is important to underscore the idea that during an investigation, Wallas (1927) conceived of these stages as in a constant state of overlap with each other. "Even in exploring the same problem, the mind may be unconsciously incubating on one aspect of it, while it is consciously employed in preparing or verifying another aspect" (p. 82). This statement indicates that while one hemisphere is in predominate control of the activity of the investigator, the other is still active, but in a subtle, non-intervening manner. Polanyi (1964) would translate this to mean that the hemisphere and corresponding stage of inquiry in predominate control directs the "focal awareness" of the investigator, whereas the particular hemisphere in the background is directing the "subsidiary awareness" of the individual.

Conclusion

As defined in the rationale section of Chapter One, scientific inquiry is a two-component problem-solving operation. Keeping in mind that there is an almost instantaneous interaction between the cerebral hemispheres in the normal person, and that Wallas (1927) views his stages as in an overlapping state, Table 5 presents the idealized flow of the inquiry process. Included in this table are two components of scientific inquiry and their relationship to both the information processing strategies of each hemisphere and the stages of the Wallas model.

Koestler (1964) analyzes the inquiry processes of many scientists and mathematicians including Darwin, Kepler, Plank, deBroglie, Poincaire, Faraday, Einstein, and Fleming. He concludes (as supported in Table 5) that science is a "branch of knowledge which operates predominantly with abstract symbols, whose entire rationale and credo are objectivity, verifiability, logicality, turns out to be dependent on mental processes which are subjective, irrational, and verifiable only after the event" (p. 147). In terms of the information processing evidence presented in this study, the above statement translates as such: science is a branch of knowledge operating predominately with left hemispheric strategies for testing hypotheses which are dependent upon right hemispheric strategies for their generation.

With respect to the first hypothesis of this study, it

Table 5

A Description of Scientific Inquiry

Stages of Wallas Model	Process	Cerebral Hemisphere in Operation	Component of Scientific Inquiry
	The investigator is confronted with a problematic situation		Creation of stress and therefore motivational energy for inquiry
PREPARATION	Through deduction and induction, the investigator engages in a fruitless analysis within one frame of reference	Left	
INCUBATION	Guided by intuition, the investigator searches and selects from among other matrices	Right	HYPOTHESIS GENERATION
ILLUMINATION	Combination of Preparatory frame with the Incubatory frame to produce plausible hypothesis.	Right-Left	
VERIFICATION	Through deduction and induction, the hypothesis is analyzed and either confirmed or disconfirmed, or revised.	Left	HYPOTHESIS TESTING

is necessary to synthesize the information presented in this chapter in relation to the generation component of scientific inquiry. When considering this information, it is possible to identify explicit characteristics of this component. Since the generation of a hypothesis occurs during the incubation and illumination stages of the Wallas model, these characteristics are classified as to their occurrence in each of these stages.

The incubation stage is defined by Wallas as a voluntary abstention from conscious thought about a problem. He implies that "conscious thought" about a problem are those mental acts which occur during the preparation and verification stages. These are the processes of induction and deduction and, as described earlier, have the logical, linear quality of the information processing strategies of the left cerebral hemisphere. It can be assumed, therefore, that during incubation an abstention from conscious thought is analogous to the type of thinking performed by the right hemisphere. Poincaire describes this type of thinking as "subtle" and "delicate," and in a form which is *felt* by the investigator. A. R. Wallace (1905) depicts an abstention from conscious thought as a "vague" form of thinking. Samuels and Samuels (1975) describe incubatory thought as a "non-ordinary state of consciousness and deals in images. . . ." (p. 259) They further define this non-ordinary thought as the "revivire" state--thinking in a state of detachment whereby intuitive thinking occurs. By using the term "voluntary," Wallas is implying that the investigator purposefully puts himself/herself into a receptive environment that facilitates the occurrence of this right-hemispheric, revivire state. Such environments include: relaxing, thinking about other matters, taking walks, meditation, being half-asleep, or dreaming (Samuels and Samuels, 1975).

It is important to note that when the hypothesis generating component is considered wholistically, the incubation stage is considered to be more important than the illumination stage (Samuels and Samuels, 1975). In viewing an inquiry in progress, the incubation stage takes up significantly more of the investigator's time than does the illumination stage. In fact, the hypothesis generating component has in many minds become synonomous with the incubation stage. Therefore, some of the evidence to support a characteristic of incubatory thought has necessarily come from individual definitions of the generation component.

When an investigator is in a state of incubatory thought about a problem, his/her thinking has five characteristics. These qualities are listed below with the appropriate evidential support that is presented in this study.

Incubatory thought is:

1. Synthetic
    a. Polanyi's definition of the generation component.
    b. Empirical and theoretical research by Levy, Sperry, Seamon and Gazzaniga, Kimura, and Bower.

   - c. Bruner's definition of the "intuitive mode of thinking."
   - d. Maslow's definition of "experiential knowing."
   - e. Samples' definition of the "metaphoric mind."
   - f. Koestler's definition of "thinking aside."
   - g. Poincaire's "hooked atom" analogy.
   - h. Case study report of A. R. Wallace.

2. Imaginary
   - a. Polanyi's definition of the generation component.
   - b. Empirical and theoretical research by Levy, Seamon and Gazzaniga, Bower, and Kimura.
   - c. The Jackson-Bogen "duality hypothesis."
   - d. Samples' definition of the "metaphoric mind."
   - e. Case-study report of Kekule.
   - f. Samuels and Samuels' definition of incubation.
3. Timeless
   - a. Empirical and theoretical research by Levy, Seamon and Gazzaniga, Bower, and Kimura.
   - b. Maslow's definition of "experiential knowledge."
   - c. Samples' definition of the "metaphoric mind."
   - d. Case-study report of A. R. Wallace.
4. Intuitive
   - a. Medawar's definition of the generation component.
   - b. Polanyi's definition of the generation component.
   - c. Bruner's definition of the "intuitive mode of thinking."
   - d. Samples' definition of the "metaphoric mind."

   - e. Koestler's definition of "thinking aside."
   - f. Poincaire's "hooked atom" analogy.
   - g. Samuels and Samuels' definition of incubation.

5. Metaphorical
   - a. Samples' definition of the "metaphoric mind."
   - b. Case-study report of A. R. Wallace.
   - c. Case-study report of A. Kekule.

The illumination stage (or the "Eureka experience") occurs at the end of the incubation stage, and is totally dependent upon the allowance for incubatory thought. During this stage a newly generated hypothesis becomes verbalized. The chief characteristic of illuminatory thought is its:

1. Suddenness
   - a. Medawar's definition of the generation component.
   - b. Bruner's definition of the "intuitive mode of thinking."
   - c. Case-study report of A. R. Wallace.
   - d. Koestler's definition of the "Eureka experience."
   - e. Case-study report of A. Kekule.

With this listing of the characteristics of the thinking that occurs during hypothesis generation, this component of inquiry is explicated. It is viewed, therefore, that the first hypothesis of this study can be accepted. From this point of explication, this study makes two applications to the teaching of science. These characteristics are related to an instructional strategy that could be used in science teaching, and these qualities are applied to two presently used science educational curricula.

Chapter III

> The ability to use fantasy and imagination is an essential part of any creative endeavor, whether it be in artistic expression or scientific discovery. (Clark, 1976, p. 67)

> Guided fantasy offers the possibility of engaging the right half of the brain in the learning process. (Roberts and Clark, 1976, p. 8)

Introduction

The first two chapters of this study examine the nature of scientific inquiry, placing a significant emphasis on the hypothesis generating component. The purpose of the next two chapters is to apply this information to the teaching of science. Chapter Three, in making one such application, examines a teaching method which encourages the generation component. It considers the second hypothesis of this study --guided imagery is an instructional strategy which fosters the hypothesis generating component of scientific inquiry.

In order for the guided imagery strategy to be identified as one that encourages this component, four conceptual operations are required. First, the definitions and assumptions of guided imagery are given. Second, the theoretical orientation of the strategy is considered. Third, the characteristics of the guided imagery strategy are identified.

The final operation considers the applicability of this strategy to the teaching of science. After these operations are performed, a decision concerning the acceptance of the second hypothesis is made.

As stated in the previous chapter, the hypothesis generating component consists of the incubation and illumination stages of the Wallas Model. It is also contended that the illumination stage is totally dependent upon the occurrence of the incubation stage. For purposes of this discussion, the guided imagery strategy is examined for its capability to foster incubatory thought. It is assumed that if incubatory thought is encouraged, there is a corresponding encouragement of the illumination stage. In addition to this parameter, this discussion is predominately logical and inferential in nature. There are as yet no definitive empirical studies which indicate the applicability or the effectiveness of guided imagery in fostering incubatory thought in science teaching.

Definition and Assumptions of Guided Imagery

The purposeful use of imagination as a tool for human growth and development has taken place for many centuries. Individuals who have employed imagination techniques within this century include C. G. Jung, Robert DeSoilles, Roberto Assagioli, and George I. Brown. The term "purposeful" is important as Miller and Vargiu (1975) explain: "Certainly one of the keys to the proper use of imagination is purposiveness. Uncontrolled or idle daydreaming is imaginative, and may have uses but it is often inefficient" (p. 120). An instructional strategy is a purposeful attempt to lead the learning process in a general or specific direction. A strategy which facilitates the imagery processes of an individual is called guided imagery (also called guided fantasy and directed daydreaming). During inquiries in science teaching, it is a method which places the learner in a state of incubatory thought (Samuels and Samuels, 1975).

The guided imagery strategy is based upon four assumptions. The first one is that although the imagery processes may be underdeveloped in some people, the potential for imagery in man is probably universal (McKellar, 1972; Doob, 1972). Second is that images are "constructed according to standard, universally shared programs" within the brain (Holt, 1972, p. 29). Third is that an individual, while exposed to the guided imagery strategy, thinks in images. Samuels and Samuels (1975) explain that an imagery experience which is directed in a purposeful direction "occurs [within the person] at a level of non-ordinary consciousness which produces inner imagery" (p. 256).

The fourth assumption which underlies the use of guided imagery concerns the conditions such a strategy creates in an educational setting. The conditions created by guided imagery foster an introspective expectancy within the learner, thereby enhancing the probability that imagining will occur (Neisser, 1972, Doob, 1972). "Another way to look at it is that people are programming their biocomputer to be in readiness to accept a visualization experience" (Samuels and Samuels, 1975, p. 135). In scientific inquiries some hypotheses are generated through the imagery process. The Kekule case-study report suggests this contention. Since educational settings provide a more structured atmosphere for incubatory thought than in the natural environment of a scientist, the introspective expectancy created by the guided imagery strategy is critical. Kekule studied evidence about the structure of organic molecules at different times of the day; his dream image of a "ring of serpents" came late at night. This image Kekule experienced is called an "unbidden image," and occurs in conjunction with the intent of an investigator to solve a problem (Horowitz, 1972). An instructional strategy which applies imagery intends to model and expedite the occurrence of unbidden images within the framework of a classroom environment. As Samuels and Samuels (1975) state: " . . . the conditions under which people receive spontaneous visualizations, can be consciously created, reproduced, and controlled" (p. 256).

Theoretical Orientation of Guided Imagery

In order to use an instructional strategy which employs imagery, it is necessary to have an awareness of the imagination process. Images are perceptual representations or mental pictures which are constructed in the brain. The raw material for images is neurologically encoded sensory information that arises from either of three sources: from memory, from the effect of external stimuli on the sense organs, or from processes (other than memory) internal to the sensory system (Holt, 1972).

As demonstrated in the previous chapter of this study, incubatory thought has the qualities of being imaginary, timeless, synthetic, metaphorical, and intuitive. Guided imagery experiences satisfy all of these characteristics. They are by definition imaginary. They are timeless. Gordon (1972) believes that a major function of imagery experiences is that it allows the individual "to span time and so relate objects and experiences from the past to objects and experiences in the present" (p. 78). Also, imagery experiences can operate to span time in a future direction. The timeless nature of incubatory thought has also been described by Levy (1974) as a simultaneous interaction between objects and events. Horowitz (1972) depicts a function of imagery experiences as representing "both self and object and the relationship between self and object in a simultaneous format. This quality of simultaneity allows condensation of multiple meanings into a single format" (p. 300).

Guided imagery experiences are synthetic in nature. As Gordon (1972) writes: "through the image we sift, and select and render down to a manageable scale both the world of objects and our own human experience" (p. 75). This characteristic is consistent with the synthetic nature of incubatory thought, since (as depicted by Medawar, Koestler, and Poincaire) the investigator during incubation sifts and selects from many different frames of reference. Imagery experiences are also *metaphorical*. Samuels and Samuels (1975) and Samples (1976) depict incubation as a process where metaphorical connections are made from images experienced by the investigator. Finally, guided imagery experiences are *intuitive*. Crampton (1969) writes that these experiences "can be of great value in stimulating intuition" (p. 150). This contention is supported by the theoretical positions taken by Roberts and Clark (1976) and by Samuels and Samuels (1975).

In summary, the guided imagery strategy creates a state of incubatory thought for the learner. This conclusion is supported directly from the definition and assumptions of the strategy, and indirectly from the theoretical relationship between the imagery process and the characteristics of incubatory thought. In order to see how this strategy operates in a science classroom, it is necessary to identify the characteristics of guided imagery.

Characteristics of Guided Imagery

In general, "the use of imagination is one of the most rapidly spreading new trends in psychology and education" (Miller and Vargiu, 1975, p. 119). Within the context of science teaching, the guided imagery strategy can be used to foster hypothesis generation. This method has four major characteristics which allow the student to engage in incubatory thought:

1. The students at the beginning of the experience are requested to become relaxed and calm.
2. The students are requested to imagine objects, persons, or events which are related to the problematic situation confronting them.
3. The students are requested to become aware of their feelings and bodily sensations during the imagery experience.
4. The students are requested to put themselves in the place of the object(s), person(s), and/or event(s) under consideration.

It is suggested that these characteristics can be applied to the creation of a guided imagery experience which is relevant to any concept under consideration in inquiries that occur in science classrooms. An example of a guided imagery experience is presented to demonstrate how these characteristics are applied in creating an activity which is relevant to a particular science concept. This illustration is created to allow for incubatory thought about a problematic situation which is found in the Clay Boats unit of the Elementary Science Study (1967). This unit, which examines the concept of "bouyancy," is designed for grades four through eight.

The students in this unit are given 100 grams of clay, a container of water, and some paper clips. They are asked to change the clay into a shape that will float, and then are asked to see how many paper clips can be placed onto the shape without it sinking. After the students have had time to explore these materials, test constructions, and to record their data (the preparation stage of the Wallas Model), the teacher would present the following guided imagery experience (adapted from Stevens, 1973).

"The Clay Boat Fantasy"

> Take your clay and find a comfortable spot to sit, with some space around you. . . . Now take a few minutes to explore even more your piece of clay. . . . Feel its texture and weight. . . . Feel the way it changes shape as you explore it with your fingers. . . . Try different ways of shaping it--squeezing, patting, rolling, pushing, etc. . . . Discover what the clay is like and what it is capable of. . . .
>
> Now that you have explored the clay, shape it all together into a fairly round ball and sit it gently in front of you. . . . Close your eyes, sit in a comfortable position, and think about your hands and fingers, that have just been exploring the clay. . . . Notice how your hands and fingers feel. . . . Now think about different parts of your body. . . . Notice and become aware of what you feel in each different part of your body. . . . Try to become more relaxed. . . . Notice and become aware of how you are breathing. . . . Do not try to change how you are breathing, but just try to become more relaxed with each breath you take. . . .
>
> Now keeping your eyes closed, I want you to try to see a picture in your mind of the round ball of clay that is in front of you. . . . Imagine that it will slowly change itself into the shape of the boat that you made earlier. This is the boat that held the most paper clips without sinking. . . . Now I want you to become this boat. . . . How do you feel as this floating piece of clay? . . . Notice how you feel in each part of your body. . . . What is it about you that makes you float? . . . Where are the paper clips placed on you? . . . How does it feel to have this weight on you? . . .

Now I want you to become yourself again. . . . Think about what it was like to become a piece of clay. . . . Now I want you to imagine that you are one of the best cargo boat builders in the world. . . . How do you feel as this person? . . . What is your life like? . . . The kind of boats that you build are made to hold huge amounts of materials, and are not made to travel fast. . . . You know what makes a boat float, and where and how much of a load it can carry without sinking. . . . What is the shape of your boats? . . . How great a load will they carry, and where is it placed? . . . Now I want you to think and imagine what cargo boats of the past looked like. . . . Imagine what they will look like in the future. . . . Compare these boats with the boats you build. . . . How are they alike? . . . How are they different? . . .

Now I want you as this boat builder to imagine a picture of your very best boat The one which holds the most cargo. . . . How is this boat alike or different from the clay boat you made earlier? . . .

Now, keeping your eyes closed, become yourself again. . . . Try to see a picture again of the round ball of clay that is in front of you. . . . Imagine that it will slowly change and shape itself into the very best cargo boat you made when you were a boat builder. Remember that this is a boat made to carry cargo and not made to go very fast. . . . Don't try to change this imaginary ball of clay; let it change itself slowly into your boat. . . . Whatever it does, just watch it closely as it changes, without interference from you. . . .

Now I want you to reach out to the real ball of clay that is in front of you. . . . Hold it gently in your hands for a little while. . . . Notice how your hands and fingers feel. . . . Get to know your piece of clay again. . . .

Now, with your eyes closed, I want you to make out of the clay a shape that is the same as the very best cargo boat you made when you were a boat builder. . . . As much as you can, let the clay and your fingers lead you in your creation. You will have about 10 minutes to do this. . . .

(Give a little warning near the end of the time period.)

Now slowly open your eyes and look at what you have made out of the clay. . . . Continue to work on it a little if you wish so that you come closer to your picture of the cargo boat.

After this experience, the students would be requested to go over to the containers of water to see how many paper clips their newly designed clay boat will carry. This effort can be considered as an attempt to test their hypothetical boat constructions. There is, of course, no guarantee that each student's newly designed boat (a plausible hypothesis) will exceed the cargo capacity of his/her earlier design. But it is just as certain that a newly designed, hypothetical boat construction requires some form of incubatory thought. To provide such thought is the only purpose of a guided imagery experience.

Upon examination of the "Clay Boat Fantasy", the four characteristics of the guided imagery strategy, which are applied in its creation, can be identified. A relaxed atmosphere is produced by having the students close their eyes, relax their bodies, and become aware of their breathing patterns. Also, this environment is facilitated by the slow, calm, and deliberate pace in which the imagery experience is read to the students. This aspect is illustrated by the three-dot pauses (. . .) scattered throughout the written text of the fantasy. The case-study reports of Kekule and A. R. Wallace indicate that each was in a relaxed atmosphere and state of mind during incubatory thought. Samuels and Samuels (1975) write that "body relaxation makes it more likely that people will visualize" (p. 135).

The second characteristic of guided imagery is applied by requesting the student to imagine objects, events, or persons related to boat construction and bouyancy. By having the students imagine cargo boats of the past and future, an attempt is made to lead the student away from existing structures into a more wholistic frame which transcends time boundaries. As Stein (1974) states: "Successful hypothesis formation depends on great measure on an individual's not being fixated on existing stimuli and structures" (p. 23).

At three points during the "Clay Boat Fantasy," the student is asked to become aware of his feelings and bodily sensations. The first place occurs during the initial period of relaxation. The other points occur in relation to the fourth characteristic of guided imagery. Requests are made of student awareness of feelings and bodily sensations in conjunction with requests that the students imagine that they are both a piece of clay and a foremost boat builder. By having the students imagine themselves as an object, person, or event, the attempt is made to bring about a close, personal, intuitive identification with these entities. W. J. J. Gordon (1961) has named the identification process "personal analogy." He believes this process is critical to the creation of a state of incubatory thought.

The "Clay Boat Fantasy" is designed to be relevant to a whole class of students who are engaged simultaneously in an examination of a specific conceptual unit of an elementary school science curriculum. This design is consistent with the second characteristic of the guided imagery strategy. There may be instances in science classrooms, however, where students are individualized. In this instance, several different concepts and corresponding inquiries are considered simultaneously. Two currently used programs which operate in this manner are the Intermediate Science Curriculum Study (ISCS) and the Individualized Science Instruction System (ISIS). Under an individualized condition, it would be ineffective for an instructor to develop and present to the entire class an imagery experience that is conceptually relevant to only a few students. The following is an example of a guided imagery experience (adapted from Stevens, 1973) that could be utilized in these situations.

"The Wise Person"

> Close your eyes, and try to become more comfortable. . . . Think about different parts of your body, and notice what you feel in each different part. . . . Try to become even more relaxed in each part of your body. . . . Notice how you are breathing. . . . Do not try to change how you are breathing, but try to become more relaxed with each breath you take. . . .
>
> I want you to imagine that you are walking up a trail in the mountains at night. There is a full moon which lets you see the trail easily, and you can see quite a lot of your surroundings. . . . What is this trail like? . . . What else can you see around you? . . . Just ahead there is a small side trail that leads up higher to the cave that is the home of a very wise person who can tell you the answer to any question. Turn off onto this side trail and walk toward the wise person's cave. . . . Notice how your surroundings change as you move up this trail and come closer to this cave. . . .
>
> When you arrive at the cave, you will see a small campfire in front of it, and you will be able to see faintly the silent wise person by the light of the dancing flames of fire. . . . Go up to the fire, put some more wood on it, and sit quietly. . . . As the fire burns more brightly, you will see the wise person more

clearly. Take some time to really become aware of him--his clothes, his body, his face, his eyes. . . .

Now ask the wise person some question about the problem you are investigating. As you ask the question, continue to watch the wise person, and see how he/she reacts to what you say. This person might answer you with words alone, or this person might also answer you with a gesture or facial expression, or this person might show you something. . . . What kind of answer does the wise person give you? . . .

Now become the wise person. . . . What is your life like as this wise person? . . . How do you feel as this person, and what are your feelings toward this visitor who questions you? . . . What do you say to this visitor--whether in words, gestures, or actions? . . .

Become yourself again and continue this conversation with the wise person. . . . Do you understand what this person is saying to you? . . . How do you feel toward this wise person? . . .

Now become the wise person again and continue the conversation. . . . Is there anything else you can say to the visitor? . . .

Become yourself again. You will soon have to say goodbye to the wise person. . . . Say anything else you want to before you leave. . . . Now turn away and slowly start walking back down the mountain trail. . . . As you walk back down the trail, look at the trail carefully, so that you will remember how to find your way back to the wise person when you want to visit again. . . . Be aware of your surroundings, and how you feel. . . .

Now keep your eyes closed and come back to your place in this room. . . . Think about your visit and upon the answers the wise person gave you about your problem. . . . Open your eyes.

In "The Wise Person" fantasy, there is a change in the degree to which the relevancy characteristic of the guided imagery strategy is applied. This change in degree is toward a more general direction when compared to the "Clay Boat" fantasy. The students ask the "wise person" some question about a problem they are investigating. This creates the flexibility necessary to operate in an individualized teaching situation. Except for this change, "The Wise Person" experience satisfies the other characteristics of guided imagery to the same degree that the "Clay Boat" fantasy fulfills these qualities.

The student establishes a dialogue with the "wise person" in order to facilitate incubatory thought about a problem he/she is investigating. The idea of communicating with this "person," through gestures, facial expressions, or by being shown something, is consistent with the non-verbal nature of the information processing strategies of the right hemisphere. Miller (1975) holds that this dialogue is based on "the assumption that within each of us is an endowment of wisdom, intuition, and a sense of purpose, which can become a source of guidance in everyday life" (p. 123). This activity can be used in conjunction with any problematic situation. By asking the student to make a careful note of the pathway to the wise person's cave, the stage is set for him/her to repeat this journey with the same or different problems, with or without specific instructions from the instructor.

Because of the subjective nature of all imagery experiences, each student may have a unique picture of the "wise person." The following are three descriptions of the wise person from individuals who have experienced this journey.

a. "Usually he is a Wise Old Man who looks something like the Lama Gouinda, whose pictures I have seen. He is old, slender, bearded, and dressed in ritual robes. He is Tibetan and ascetic, and has a very loving and blissful expression." (Miller, 1975, p. 127)

b. "there is a young man. He is dressed like a monk and talks about larger issues than the first one. He doesn't communicate in many words, either; he indicates an experience to be had." (Miller, 1975, p. 127)

c. "The Self appears serene, clothed in white . . . strong (though dimly seen) and radiant--like the Christ in Fra Angelico's 'The Transfiguration.' He speaks to me . . . , He has the quality of a teacher. Interested and concerned, but detached. If he demands anything, he demands to be embraced. He opens himself to that. Take him or leave him, is what he says. He shows me directions and possibilities, leaving me to follow them or not. He is there. He is not to be chosen." (Miller, 1975, p. 130)

Applicability of Guided Imagery

Whenever a problematic situation confronts the student, and after a fruitless analysis of it occurs, the concept under consideration can be transformed into a guided imagery experience. The transformation is based on the characteristics of the guided imagery strategy. Through the use of guided imagery, time is given to the student for an examination of his/her problem from many angles, in the search for what Koestler calls an "auxiliary matrix." Research evidence (Fox, 1914; Rugg, 1963; and Samuels and Samuels, 1975) indicates that when individuals are confronted with a problematic situation, they produce an abundance of mental images as a natural adaptation to solving this conflict. Guided imagery taps this source.

The instructor serves as the leader in making decisions about the amount of incubation time to allow for each problematic situation for each student. It may be necessary to allow this time to extend for several class periods, which may include more than one imagery activity. Because of the imaginary, intuitive, wholistic, metaphorical, and timeless nature of the incubation stage of scientific inquiry, a great deal of latitude must be imparted to the instructor in applying the guided imagery strategy. Also, this strategy may be used in conjunction with other instructional methods which allow for incubation. Some examples include Synectics (Gordon, 1961), Deferred Judgment (Parnes, 1962) and Meditation (LeShan, 1975). In order to provide a clearer perspective on the guided imagery strategy, two of these methods are discussed briefly.

Parnes (1962) has demonstrated that in relation to a given problem, students who used the technique of "deferred judgment" received twice as many plausible hypotheses as students who did not. Deferred judgment is a technique which allows for incubatory thought (Samuels and Samuels, 1975). In this method the teacher instructs the students, who are working on a problem, to free themselves of any inhibitions, to let their minds wander fully, and to let their imaginations soar. The teacher decides the amount of time this deferred judgment takes. When compared to guided imagery, this technique is much less structured, and probably does less to create the introspective expectancy that guided imagery does.

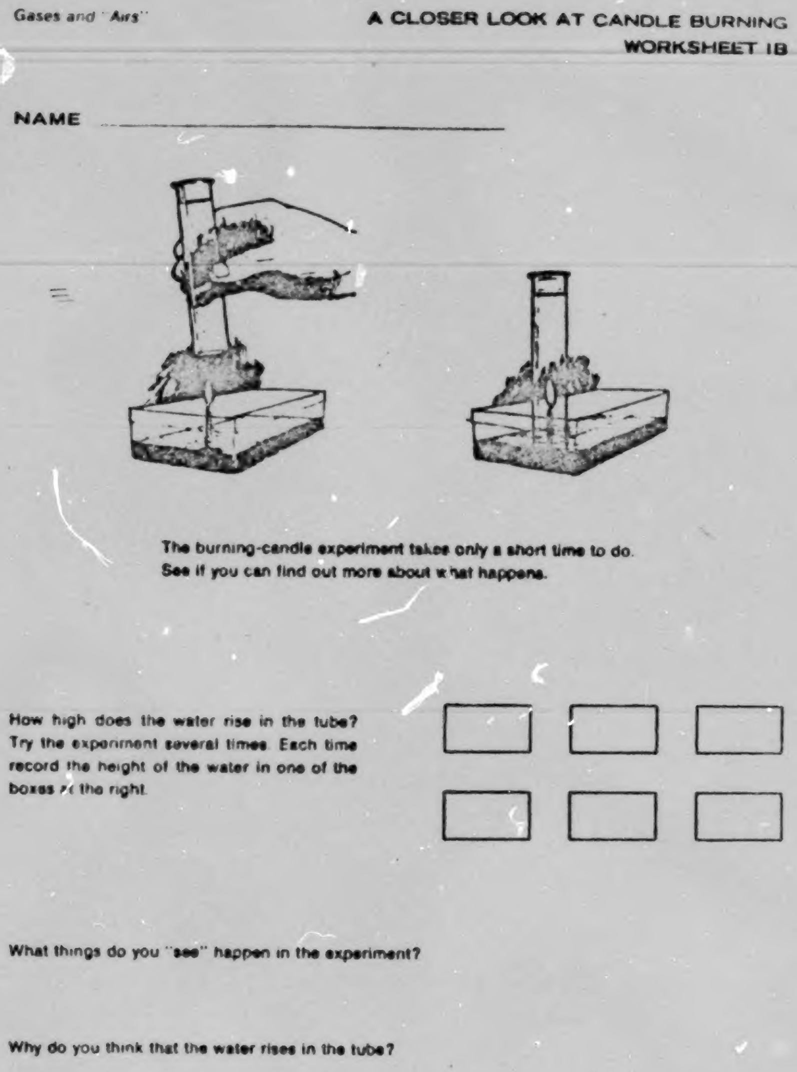
As mentioned in the previous chapter, meditation is listed as one of the states of mind in which incubatory thought can occur. Meditation experiences "are designed to produce an alternation of consciousness--a shift away from the outward-oriented, linear mode and toward the receptive, quiescent mode" of information processing (Ornstein, 1972, p. 123). There are several kinds of meditation experiences. In one type, the students would be requested to close their eyes and to relax by becoming aware of their breathing patterns. They would be told to return to an awareness of these patterns whenever their minds began to wander. By returning to a concentration on breathing patterns, the wandering of the mind would be stopped. The teacher would also instruct the students that if their minds wander into an area that is related to their problem, they can remain in this area and should not return to their breathing patterns (LeShan, 1975).

When comparing a meditation experience to a guided imagery experience, it can be seen that they have a similar intent. As in guided imagery, meditation allows the student to "activate the right-hemispheric mode of consciousness and thus develop intuition and perception" (Miller, 1976, p. 132). This activation occurs through the creation of a relaxed state of mind for the student. Beveridge (1957) believes that the relaxed, calm mind enhances incubatory thinking. The major difference between meditation and guided imagery is that guided imagery is a more specific and structured method of facilitating incubatory thought.

The guided fantasy method is applicable to all grade levels where scientific investigations are taking place. The imagery function in man is an earlier form of information processing than the verbal, logical form of thinking (Horowitz, 1972). An infant processes information in imagery forms before the appearance of what Piaget (1968) calls "pre-operational" thinking, and continues to think in images throughout life. (Pre-operational thinking occurs when the individual attaches verbal labels to experiences and begins to classify them.) Probably the best indicator for the use of a method, which employs imagery to foster hypothesis generation, is the student's ability to perform the thinking required in testing hypotheses.

Since most science educational curricula do not use guided imagery as an incubatory technique, the teacher may have to modify these materials in order to incorporate imagery experiences. An example of this modification comes from the Gases and "Airs" unit of the Elementary Science Study (1967). This unit investigates the properties of a gas when it interacts with common objects in the environment. It explores the processes of oxidation as it occurs during combustion, rusting, and metabolism. The beginning activities examine the burning of a candle. Figure 4 illustrates the apparatus used for these activities and is taken from the worksheet which is given to the student.

Once the candle is lit and covered, it eventually goes out, and there is a subsequent rise in the water level within the container. The question: "Why do you think that the water



Gases and "Airs"

A CLOSER LOOK AT CANDLE BURNING
WORKSHEET IB

NAME ______________________

The burning-candle experiment takes only a short time to do.
See if you can find out more about what happens.

How high does the water rise in the tube? Try the experiment several times. Each time record the height of the water in one of the boxes at the right.

What things do you "see" happen in the experiment?

Why do you think that the water rises in the tube?

Figure 4. Initial Activity Materials for Gases and "Airs"

rises in the tube?" may assume knowledge of two natural laws. In order to provide some plausible hypotheses, the student must understand that the candle consumes part of the gas (the oxygen) in the cylinder when it burns, and must know that there is a natural tendency for atmospheric pressure to be equally applied on all surfaces of the earth. Therefore, if the candle uses up some of the air in the container, the pressure is decreased, which causes a greater pressure on the outside of the container. To reach an equilibrium condition, the space inside is shortened (by the rise in the water level), which increases the pressure inside to equal the pressure on the outside of the container.

The designers of the unit expect that the student has a general understanding of these two laws, and intend to develop _specific_ knowledge about their relationship. Furthermore, they predict that the students, when asked questions about their observations as in Figure 4, will make an incomplete hypothesis: a hypothesis which attributes the water rise as being _directly_ proportional to the amount of oxygen used up by the candle, _without_ attributing any part of the rise to the expansion and subsequent cooling of a heated gas. In classroom practice this expectation by the program developers has proven to be accurate. A guided imagery experience could be inserted before requesting the students to generate the above hypothesis. For example, the questions asked of the student in his workbook could be posed to the "wise person" in a fantasy format. The application here of guided imagery is not necessarily directed at facilitating the formulation of a complete hypothesis, since more observations are needed for this to occur. It is intended to provide students with incubation time. Although it is still likely that the incomplete hypothesis will be put forward, an imagery experience may insure its generation by more of the students than would occur without such an experience.

In order to test the above mentioned hypothesis, the unit proceeds to examine the effect of steel wool when placed inside of the container without the candle. It is observed over a period of time that the height of the water level rise is consistently one-fifth of the tube's height, and that this figure does not change when the position or amount of steel wool is modified. Next, a sequence of activities compares the effect of steel wool on a gas with the effect of the burning candle on a gas. These experiments lead to the observation that the candle, when lit, goes out instantly when placed into a container that has had steel wool in it for 48 hours. The conclusion is reached that the steel wool uses up the same part of the air that the candle needs for burning. However, subsequent activities which combine the steel wool into the container with a burning candle demonstrate that there is an additional water level rise after the initial rise which occurs when the candle is extinguished. The inference is drawn that the candle does not use up as much of the gas in the container as does the steel wool.

Through discussion the students find out that the oxygen fraction of air is equal to one-fifth of the total volume of air. Now the stage is set to compare the height the water rises in the candle-burning activities with the height of the rise in the steel wool activities. Based on the evidence accumulated, the students might predict that the "steel wool" water level rise should be higher than the "burning candle" water level rise, since the wool uses up more oxygen than the candle. When measured, however, the height of the rise inside the container with the burning candle is consistently higher than the height of the rise in the steel wool container. Through these activities the hypothesis that the water rises directly proportional to the oxygen used up by the burning candle is not confirmed. The above series of experiments may be viewed as a preparatory stage of scientific inquiry, which leaves the student (after his analysis) without a complete explanation of the observed phenomenon. At this point in the course of inquiry, a guided imagery experience could be inserted to allow for incubation. The following guided fantasy experience is developed for this problematic situation, and is derived from the basic commonalities of the imagery experience. (It is assumed that students have had previous experience with directed imagery and are in a relaxed position.)

"The Super Flea Imagery"

> Close your eyes and notice how the different parts of your body feel. . . . Try to become even more relaxed. . . . Notice how you are breathing. . . . Do

> not try to change how you are breathing, just watch how you breathe. . . . Now I want you to imagine that you have the power to shrink in size. . . . Very slowly, try to become smaller. . . . Become as small as a newborn baby. . . . How does it feel to be this little? . . .Now slowly become even smaller. . . . Become as small as a cat. . . . Notice how big everything seems to you as this animal. . . .
>
> Now become as small as a flea on the back of the cat. . . . Imagine that you are walking around on the back of the cat. . . . How do you feel as this flea? . . . Now imagine that as this flea you have superhuman powers. . . . You can move at any speed, wherever you want to, and you cannot be hurt by anything. . . .
>
> Now I want you to imagine that you are going to go inside of the container with the steel wool in it. . . . As it is covered, remember that as this flea you cannot be harmed. . . . How do you feel inside this container? . . . Notice the water rising over the next day. . . . Can you tell why the water is rising? . . .
>
> Now imagine that you leave the container and go into a different one. . . . This time you are going to travel inside the container with the candle in it. . . . As the candle is lit and covered, remember that you have superhuman powers as this flea and cannot be harmed. . . . How do you feel inside of this container? . . . Notice the water rising and the candle going out. . . . Can you tell why the water is rising? . . .
>
> Now leave this container. . . . Compare how your life was different in these two containers. . . . Now slowly become larger in size and become yourself again. . . . Return to your place in this room. . . . Open your eyes and think about what you have just experienced. . . . In small groups you may share your experiences if you want to. . . . Be sure to talk about the differences you noticed in the two different containers you were in. . . .

Based on the class discussion which focuses on the different environments of the two containers, the heat present when the candle was lit will probably be mentioned as a significant difference. The instructor may now lead the discussion to the effect heat has, if any, on the differences observed between the height the water rises in the two containers. One hypothesis that may be generated is that heat, together with the amount of oxygen used by the candle, may be causing the water level rise in the candle container to be higher than the level measured in the steel wool container. Subsequent activities in this unit examine changes in gases when heated. This newly generated hypothesis is eventually confirmed, and a complete hypothesis, containing multiple causes to explain an observed effect, is verified. These subsequent series of activities may be called the testing component of scientific inquiry.

The above use of a guided imagery experience to allow and encourage incubation is inserted within the normal design and sequence of activities which make up the Gases and "Airs" unit. This type of modification could occur within any designed sequence of activities where inquiries take place in science teaching.

Conclusion

This chapter considers the guided imagery instructional strategy as an example of a teaching method which fosters hypothesis generation in scientific inquiry. Based on the information presented, it is demonstrated that the strategy is consistent with the qualities of incubatory thought, and that it is in a form which can be applied in the teaching of science. It is concluded that guided imagery can foster the generation component for students who are engaged in scientific inquiries. The second hypothesis of this study is, therefore, accepted.

Chapter IV

> The shrewd guess, the fertile hypothesis, the courageous leap to a tentative conclusion--these are the most valuable coin of the thinker at work, whatever his line of work. Can school children be led to master this gift? (Bruner, 1963, p. 14)

Introduction

The purpose of this chapter is to apply the characteristics of the hypothesis generating component to two contemporary science curriculum projects. These projects are the Science Curriculum Improvement Study (SCIS) and Essence I. The hypothesis under consideration in this chapter is that the SCIS and Essence I programs can be examined and evaluated with respect to the encouragement each gives to the hypothesis generation component of scientific inquiry. These curricula are selected as being representative of instructional programs presently used in science teaching.

As discussed in the rationale section of the first chapter, the definition of scientific inquiry encompasses a knowledge and an inquiry aspect. Also, that the teaching of science has shifted its emphasis toward the inquiry aspect and away from the knowledge component. This shift is reflected in the huge developmental effort of the 1960's toward curricula which focus on more laboratory type experiences for students than was the case in traditional science textbook programs prior to this time. The Science Curriculum Improvement Study (SCIS) is selected and treated first in this chapter because it is representative of this effort. Also, as discussed in the rationale section, the shift toward the inquiry aspect of scientific literacy is in essence a shift more toward the hypothesis testing component than toward its complementary partner. The Essence I program is selected as a later curriculum effort that represents an attempt to balance the overall emphasis in science curricula development by focusing on the hypothesis generating component. Figure 5 represents these evolutionary changes in teaching for scientific literacy.

In relation to the hypothesis under consideration in this chapter, which is that SCIS and Essence I can be examined and evaluated with respect to the encouragement each gives to the hypothesis generation component of scientific inquiry, the following sub-questions are examined:

1. During scientific inquiries, to what extent do SCIS and Essence I encourage synthetic, wholistic thinking for each student?
2. During scientific inquiries, to what extent do SCIS and Essence I encourage imaginary and metaphorical thinking for each student?
3. During scientific inquiries, to what extent do SCIS and Essence I encourage the timeless nature of incubatory thought for each student?
4. During scientific inquiries, to what extent

Figure 5

Shifts in Emphasis in Teaching for Scientific Literacy

Type of Science Educational Program	Types of Emphasis in Teaching for Scientific Inquiry			
	Knowledge	Process of Inquiry		
		Problematic Situation	Generation of Hypothesis	Testing of Hypothesis
1. Traditional textbook science programs	*			
2. Science programs of which SCIS is a representative example.		*		*
3. Science programs of which Essence I is a representative example.		*	*	

do SCIS and Essence I encourage the
intuitive nature of incubatory thought
for each student?

These four aspects are derived directly from the elements inherent in the hypothesis generation component of scientific inquiry, with one exception. The element not considered in this discussion is the one which describes the suddenness in which hypotheses are formulated. This is the illumination stage of inquiry that follows incubatory thought about a problem. While this stage is an integral part of the generation component, its occurrence in inquiries is totally dependent upon the presence of the incubation stage. Since this element is only indirectly dependent upon the structure of a particular science program, it is not considered in this evaluation of the third hypothesis of this study. It is assumed that an encouragement of incubatory thought provides a corresponding encouragement of the illumination stage.

In considering each science program, the structure of this chapter is divided into three parts. The first part considers the following aspects of the SCIS program: (1) the background and goals of the program, (2) the conceptual framework of the program, (3) the vehicle or way in which the conceptual framework is presented to the learner, and (4) the role of the teacher in implementing the program. The second part considers the same aspects as the first for the Essence I program. The third part evaluates directly the third hypothesis by presenting evidence related to each of the four sub-questions previously described.

The Science Curriculum Improvement Study

Background and Goals of the Program

The first program that is examined is the Science Curriculum Improvement Study (SCIS). This nationally used elementary school (K-6) program is an outgrowth of a developmental period which lasted from 1962-1969. This effort (which was supported with a grant from the National Science Foundation) followed an eight-step sequence: (1) preparation of a teaching plan and design of experiments, (2) exploratory teaching in schools by the SCIS staff, (3) completion of trial materials (i.e., teacher's guide and unit kits), (4) classroom trial (one or two years), (5) additional revision by SCIS staff, (6) second classroom trial by regular teachers, (7) revisions and preliminary commercial publication, and (8) classroom trial in several centers across the United States (Karplus & Their, 1967).

A central objective of the SCIS program is the teaching for scientific literacy. The philosophy of the program developers is quite consistent with the two-part definition of scientific literacy and incorporates both aspects of it throughout the curriculum. "Essentially, scientific literacy involves an awareness of the modes of inquiry in science and some understanding of conceptual structures of science" (SCIS Teacher's Handbook, 1974, p. 6). The activity nature of the program, whereby each student engages in numerous inquiry experiences, creates an atmosphere for an awareness of how scientific concepts are discovered and verified. The SCIS program, by assuming that scientific knowledge emerges _through_ inquiry, reflects a change in emphasis on teaching for scientific literacy referred to in Figure 5. In keeping with this shift in focus, the developers of SCIS designed student activities with the following guidelines: (1) students should engage in investigations; (2) students should apply the modern scientific view; (3) students should have direct experiences with natural phenomena; (4) students should engage in discussions of their ideas and observations; (5) students should extend their investigations when these lead in interesting directions; and (6) students should become aware of the tentative nature of scientific truth (SCIS _Teacher's Handbook_, 1974).

The program developers, however, speak of "modes of inquiry" in a manner which does _not_ clearly delineate the hypothesis generating component from the testing component. These modes of inquiry progress in a similar fashion to the sequences found in previously mentioned definitions of scientific inquiry. "Basic assumptions are made, terms are defined, phenomena are observed, hypotheses are suggested, evidence is collected, data are interpreted, and information is related to existing conceptual structures of science" (SCIS _Teacher's Handbook_, 1974, p. 11).

Because this delineation between the two components of inquiry has not occurred, the major emphasis on research studies of the SCIS program has been on the hypothesis testing operations. Probable reasons for this emphasis have been given in the rationale section (pp. 3-18). A representative example of this focus is a study by Wilson and Renner (1969). In this study 15 SCIS and 15 non-SCIS teachers and their students were observed during science lessons. The teachers using the SCIS program were trained in the use of the materials and the non-SCIS teachers used their regular textbook program. The observation instrument was divided into five areas, all of which predominately measure hypothesis testing skills. These were: observation, measurement, experimentation, interpreting data, and prediction. The results of this study demonstrated that the SCIS students performed higher on all dimensions (significantly higher on observation, measurement, and prediction).

Now that the hypothesis generating component can be viewed with explicit characteristics, it is possible to examine the extent to which the SCIS program attends to this component of inquiry. This examination considers the conceptual framework of the curriculum, the SCIS learning cycle, and the role of the teacher in implementing this cycle.

Conceptual Framework of SCIS

The SCIS program is conceptually designed into 12 "big ideas" that are presented in six levels. These concepts are organized into a physical science and life science sequence. Each of these levels corresponds to a year of elementary school, and it is the intent of the program to present one physical and one life science concept at each level. For example, the first level, which is usually introduced in the first grade, considers the Material Objects unit and the Organisms unit. Table 6 illustrates the relationship between the six physical and six life science concepts. (There is also a kindergarten unit entitled Beginnings which does not organize its information in the manner just described.)

By focusing on these "big ideas," the program developers intend to shift away from a perceived emphasis found in previous elementary science programs. That is the organization of scientific knowledge into very small conceptual bits of information, specific only to a particular discipline. "These 'big ideas' form a conceptual framework that cuts across the traditional disciplines forming a structure that illustrates the unity of the sciences" (Thompson & Voelker, 1970, p. 32). The interaction concept, for instance, is introduced at the second level, and deals with the effects of objects on each other. This unit centers around physical objects, but this view of interaction is not limited just to these objects. Later levels focus on the interactions of living objects (organisms), as exemplified in the Communities concept, which examines the interactions of two or more populations (a group of organisms of the same species). Also this example points to another aspect of the SCIS conceptual framework. Once a "big idea" is introduced, it is carried forth into later levels for further examination and application.

Research evidence consistently supports the effectiveness of the SCIS program in meeting its conceptual goals. Allen (1970, 1972, 1973) conducted a series of studies to determine

Table 6

Conceptual Framework of SCIS Program

Level	Physical Science Sequence	Life Science Sequence
1	Material Objects	Organisms
2	Interaction & Systems	Life Cycles
3	Subsystems & Variables	Populations
4	Relative Position & Motion	Environments
5	Energy Sources	Communities
6	Models: Electric & Magnetic Interactions	Ecosystems

if students using SCIS were superior to students not using SCIS in terms of the program's content objectives. These studies involved first grade (1970), second grade (1972), and third grade (1973) students. Allen concludes that the SCIS program does have the internal consistency of accomplishing its content goals.

In relation to one of the sub-questions under investigation in this chapter, the broadening of scientific information in a multi-disciplinary fashion can be viewed as an encouragement of wholistic thinking. The student, who is exposed to this framework over a six-year period of time, is required to synthesize many frames of reference (or groups of "hooked atoms"). This encouragement is seen in the previous illustration about the "interaction" concept. Another example of this philosophy is viewed with the "systems" concept. When first introduced, physical systems (i.e., electrical, solution, and pulley) are examined. This idea is broadened in later units to include living systems, and to an examination of the relationship between physical and living systems --the ecosystem.

The SCIS curriculum organizes these wholistic concepts for the learner into a sequential, hierarchial format. The "systems" concept is introduced in the second level, and its various manifestations are presented at specified points throughout the other four levels. The rationale used by the developers for organizing the conceptual framework in this manner lies within the learning theories of Robert Gagne (1970) and Jean Piaget (1968).

Applications of Gagne's theory can be seen in the hierarchial arrangement of the SCIS concepts. The chief principle of this theory which is applied is that in order to comprehend a complex idea, consideration must be given to the simpler ideas inherent in it. For example, SCIS presents the concept "ecosystem" at the sixth level. The rationale for this decision is that an ecosystem is a complex concept, which deals with the interactions of communities with their environment. Experiences with communities (i.e., forest, prairie, and lake) and environmental factors (i.e., temperature, light, and water) must precede the consideration of the ecosystem. These experiences are, therefore, incorporated into earlier SCIS units.

Applications of Piaget's theory also guide the organization of the SCIS material in a linear direction. The basic principle applied is that since individuals develop intellectually in four stages (sensori-motor, pre-operational, concrete operational, and formal operational), science experiences must be designed to be consistent with these stages. During the growth of the person from birth to maturity, he/she proceeds invariably through each stage beginning with the sensorimotor. Each developmental stage directs the person's level of conceptual understanding. There are two kinds of concepts: concrete and abstract. According to Piaget, concepts are first formed by the person in the concrete operational stage (usually between the ages of 5 and 7). An individual in the concrete stage of thinking can understand concrete concepts, whereas he/she must proceed to the formal level of thinking (usually between the ages of 11 and 15) before gaining an understanding of abstract concepts. The program developers apply this theory by arranging the concept sequences in a manner that present concrete concepts while the student is primarily in the concrete operational stage, and present abstract concepts while he/she is primarily in the formal stage. For example, the first level Material Objects unit considers solids, liquids, and gases, while the six level unit considers electricity and magnetism. "The SCIS program attempts to present scientific concepts consistent with the children's intellectual growth, developing gradually higher levels of abstraction" (SCIS Teacher's Handbook, 1974, p. 3).

In general, the conceptual framework of the SCIS program can be characterized as an attempt to encourage wholistic, synthetic thinking about the domain of scientific knowledge. This encouragement is accomplished within a linear and sequential design. Hypotheses are generated through the wholistic information processing strategies of the right hemisphere. Without empirical data, it is not possible to discover whether a linear, sequential organization of a wholistic conceptual framework would significantly effect the generation of hypotheses by a student. To date there has been no research which provides an insight into this question.

The SCIS Learning Cycle

The conceptual framework of SCIS is presented to the student through the inquiry process. At the heart of this process is the learning cycle: exploration, invention, and discovery. In the exploration stage, materials are given to the student to provide an experimental background for future problematic situations which focus on the conceptual framework. During this stage "children explore materials with minimal guidance imposed in the form of instructions or specific suggestions" (SCIS Teacher's Guide--Models, 1971, p. 16).

After exploration the students require new concepts to help them interpret their observations. The assumption is that few students can phrase new concepts by themselves and, therefore, need to be provided with a name for the "new" concept and an explicit definition. The teacher provides these experiences through class discussion and demonstration. These acts constitute the invention stage. Once a concept is introduced, the student engages in problem-solving experiences, where applications of the concept occur. These experiences constitute the discovery stage.

Problematic situations arise in the course of discovery activities from either the student, the teacher, or through specific suggestions from the SCIS Teacher's Guide. Although the exploration stage experiences may be initiated through the presentation of a problematic situation, problems which are investigated in the discovery stage are more specifically designed to involve applications of a newly invented concept. A representative example of a learning cycle, which is implemented in the Models unit, illustrates further the characteristics of each stage.

Exploration Stage. It is the purpose of the Models unit to investigate magnetic and electrical interactions. In the exploration stage, the teacher demonstrates another use of the electric circuit testers which have been assembled by the students in a previous investigation. (In this previous investigation, the students used these testers as they were introduced to the concept of a closed and open circuit.) The teacher presents to the class an electric circuit puzzle. It consists of a folded card on the inside of which are six alphabetically labeled spots which are evenly spaced on the surface. The outside of the card is designed whereby holes are cut out so that only the spots can be seen. On the inside of the card pieces of aluminum foil (a conductor of electricity) are arranged in a pattern covering two or more of the spots. When assembled only the outside of the card can be viewed, and the problem is given to the student to guess the foil arrangement on the inside. The teacher demonstrates that the electric circuit tester can be used to gather evidence by discovering if any of the foil-covered spots are connected to each other (the evidence is that the bulb of the tester lights when a complete circuit is found). Each student is then given materials and is requested to create an electric circuit puzzle that others will investigate. Figure 6 pictures an example of an electric circuit puzzle and Figure 7 illustrates the directions given to the student during this exploration stage.

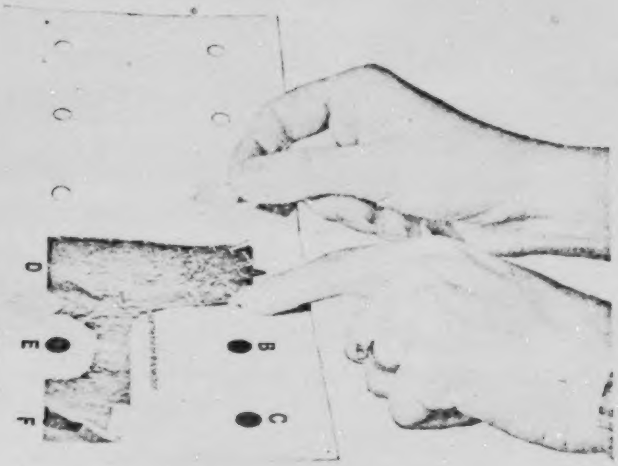
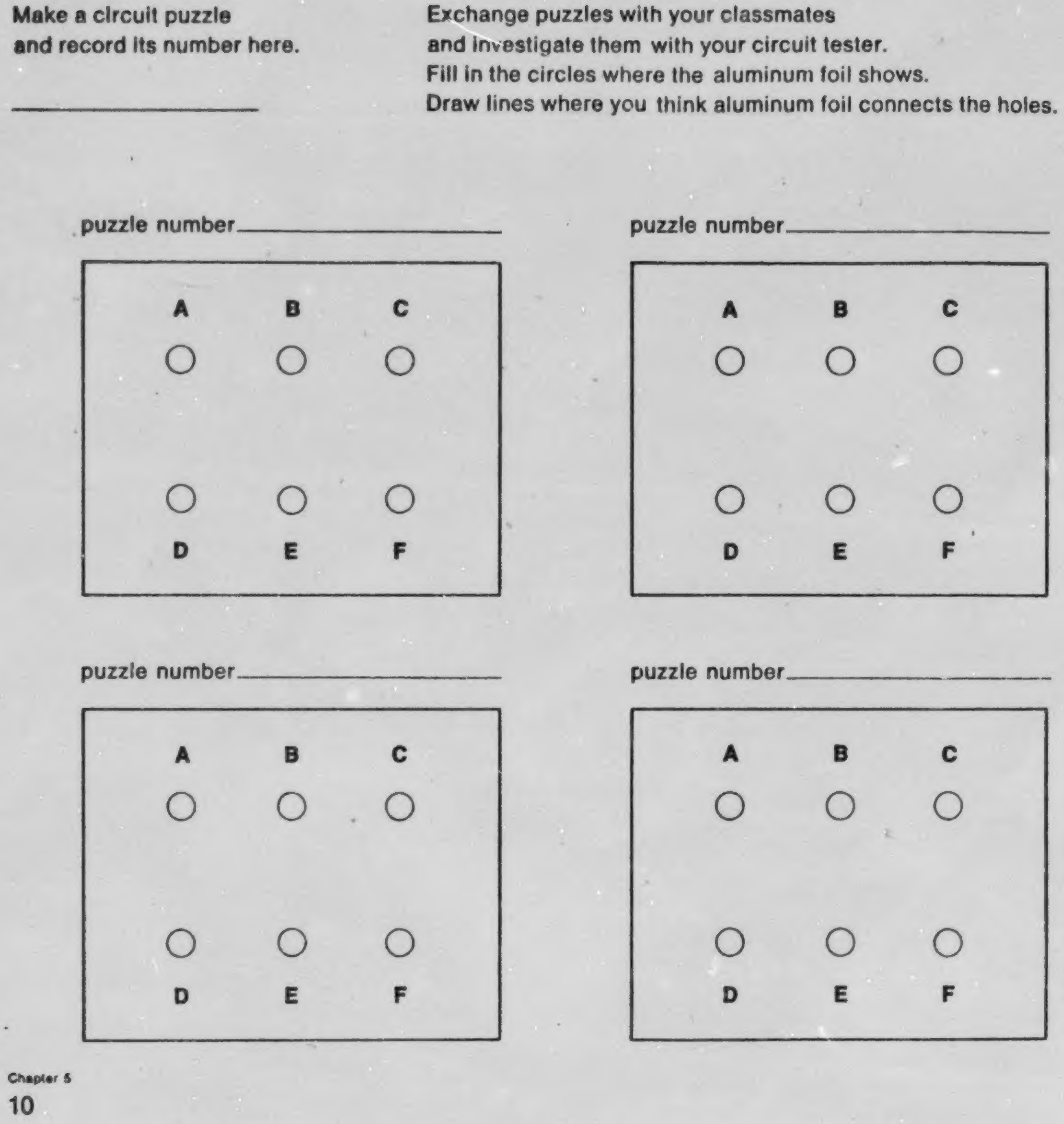


Figure 6. An Example of an Electric Circuit Puzzle Used in the Exploration Stage



Make a circuit puzzle
and record its number here.

____

Exchange puzzles with your classmates
and investigate them with your circuit tester.
Fill in the circles where the aluminum foil shows.
Draw lines where you think aluminum foil connects the holes.

puzzle number________________

A B C
○ ○ ○
○ ○ ○
D E F

puzzle number________________

A B C
○ ○ ○
○ ○ ○
D E F

puzzle number________________

A B C
○ ○ ○
○ ○ ○
D E F

puzzle number________________

A B C
○ ○ ○
○ ○ ○
D E F

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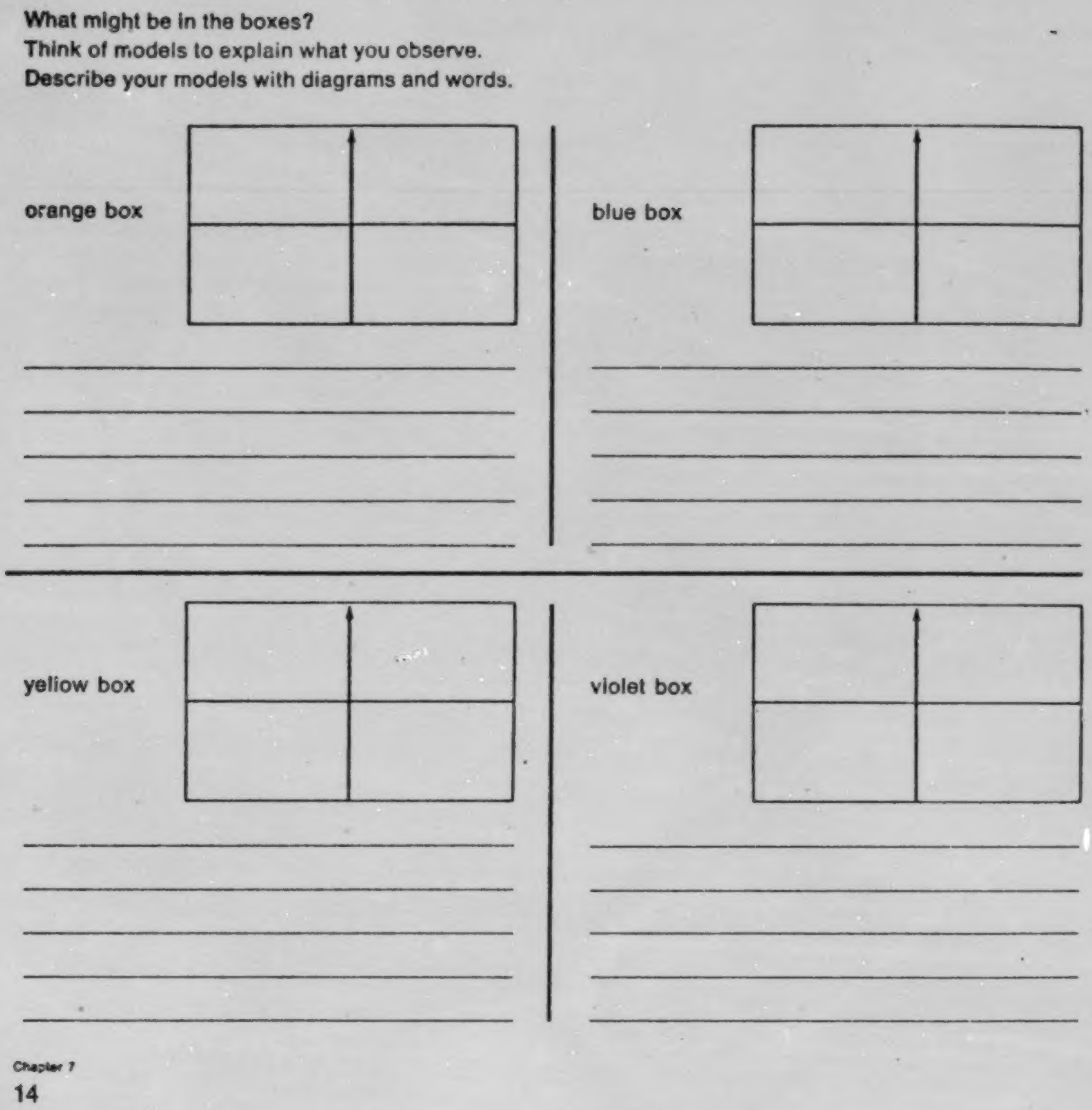
Figure 7. Student Directions in the Exploration Stage for Electric Circuit Puzzle

Invention Stage. In the invention stage the teacher conducts a discussion about the electric circuit puzzles. The students are asked to describe their experiences. The instructor then presents another puzzle, and through class discussion diagrams are put on the blackboard which describe possible foil arrangements. The teacher now tells the class that their ideas for explaining these results are called "scientific models," and writes this phrase on the board. After inventing this concept, the discovery phase ensues.

Discovery Stage. While still in discussion format, the teacher presents the "push-pull" system, and asks the class for a scientific model which explains its operation. After several possible models are discovered, another activity, which uses "inquiry boxes," follows in order to provide a different application of the scientific models concept. The inquiry box is a sealed plastic container inside of which is a round object and an obstruction which prevents its free movement. Each student receives four differently colored boxes, with a differently shaped obstruction in each box. The problem for the student is to use the ball in devising a scientific model which describes the shape of the obstruction in each of the four boxes. Figure 8 illustrates the directions given to the student in this discovery activity. Notice the use of the term "models" in these directions, which exemplifies the goal of this stage as an application of a newly invented concept.



What might be in the boxes?
Think of models to explain what you observe.
Describe your models with diagrams and words.

orange box

blue box

yellow box

violet box

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Figure 8. Directions Given to the Student in the Discovery Stage for the Inquiry Boxes

The occurrence of the three stages of the SCIS learning cycle can be observed in all of the 12 conceptual units. In each unit the cycle is repeated several times; however, the number of discovery activities exceed the number of activities designed for either exploration or invention. The goal of the SCIS learning cycle is to facilitate the inquiry process. When viewing this cycle for evidence for the encouragement of the hypothesis generating component, it becomes obvious that the program developers do not explicitly delineate this operation from the testing component. It is not stated that a specific stage of the cycle is designed for either the generation of a hypothesis or for the testing of it. Since the generation component is part of the total process of inquiry, there is a common ground where the facilitation of inquiry may also encourage the generation component. A major difficulty in the examination of this program is teasing out those attempts in the learning cycle which encourage hypothesis generation from those which facilitate the inquiry process in a general manner. It is necessary, therefore, to examine the learning cycle more closely, especially in connection with the role of the teacher, to ascertain the degree to which the generation component is encouraged.

The Teacher's Role in SCIS

As alluded to earlier, the goal of the SCIS program to teach for scientific literacy is obtained by student involvment in numerous inquiry experiences. Furthermore, the program developers established six guidelines which directed the creation of the SCIS materials. The conceptual framework and the learning cycle are developed in a manner which is consistent with these guidelines. But perhaps the critical factor in accomplishing these guidelines rests within the prescribed role the teacher plays in conducting SCIS activities.

The developers provide two major sources of information for the teacher. They are the SCIS Teacher's Handbook (1974) and the 12 Teacher's Guides which accompany each conceptual unit. The assumption which underlies the creation of these sources is that the SCIS program differs significantly from the traditional textbook programs. This difference lies in the fact that the SCIS program approaches scientific literacy from an inquiry point of view, whereas the textbook programs approach literacy from a body of knowledge point of view. A major difference in these approaches is that "in the laboratory approach, emphasis is placed on the actual manipulation of materials and experimentation by each child. This requires a classroom organization which differs from that in more traditional methods" (SCIS Teacher's Handbook, 1974, p. 3). With this assumption in mind, the developers provide information which aids the teacher in making a transition between these two approaches in teaching for scientific literacy. The first source that is considered is the SCIS Teacher's Handbook.

The SCIS Teacher's Handbook:

The SCIS Teacher's Handbook (1974) provides several general suggestions for the instructor when implementing the SCIS program. The key ones in relation to this study center around the following areas: (1) the organization of the classroom, (2) the extension of a particular lesson, (3) the questioning strategies used by the instructor, and (4) the characteristics of the creative teacher.

The Organization of the Classroom. The Handbook suggests to the teacher that during inquiries many different kinds of classroom arrangements should be used. They include (a) class discussions in large and small groups, (b) teacher demonstrations, and (c) individual and small group activities with materials. Of these arrangements, the latter one receives the most attention. The developers have produced kits of materials for each unit that provide for the laboratory-type experiences for each student. The other two kinds of classroom arrangements revolve around these experiences.

An especially important aspect of all these arrangements is the encouragement of a peer-group interaction. "One child may have an idea that can be further developed by another, thus ultimately enriching the experiences of many children" (SCIS Teacher's Handbook, 1974, p. 25). Also, several classroom arrangements reflect and produce the flexibility which is necessary not only to facilitate inquiry, but also to provide opportunity for a student to generate hypotheses. The inherent goal of these arrangements is to encourage individual participation in the course of scientific inquiries. This goal can be viewed as a general encouragement of the personal, subjective, and intuitive side of the student, which is necessary in the act of hypothesis generation.

The Extension of a SCIS Activity. The Teacher's Handbook suggests to the teacher that activities can be extended in two ways. Students can be taken to an outdoor setting for further examination of the concept under consideration, or activities can be extended to other disciplines besides science. There is the suggestion, for example, of combining SCIS activities with art forms by allowing students to draw or paint their reports of observations or experiments. "Drawing and paintings of habitats and populations may be quite useful for teachers in appraising the understanding of the children" (SCIS Teacher's Handbook, 1974, p. 20). This attempt to incorporate a visual mode of feedback can be viewed as an encouragement of the visual-image thought processes of the student. In addition, these suggestions for extending the SCIS lessons require the student to think wholistically about a particular activity, and experiences along these lines can be viewed as an encouragement of the synthetic characteristic of the generation component.

Questioning Strategies. The questioning strategies which are suggested in this handbook are designed to promote inquiry. This is especially evident by the amount of attention and encouragement given to the divergent-type of question.

This is the question which allows for many acceptable responses, such as the question: How can we find out? "Divergent questions serve to enlarge the scope of the materials being studied and to deepen the interest in the topic under study" (SCIS Teacher's Handbook, 1974, p. 21).

Porterfield (1969) conducted a study to examine the questioning behaviors of teachers who had undergone a SCIS training program. He found that these teachers ask a significantly fewer proportion of recognition and recall questions, when compared to teachers who had not undergone the training program. Moveover, the results indicate that the SCIS teachers ask a significantly higher proportion of divergent questions. These results demonstrate that the suggestion to the teacher to increase the amount of divergent questions (through a training program) has been translated into classroom practice.

Also found in this section of the handbook is the suggestion and emphasis placed on the amount of time the teacher waits after asking a student a question before making a statement. This factor is called "wait-time" and there is a suggestion that the teacher should increase the "wait-time" factor when he/she is directing discussions. This increase serves to enhance individual participation, to deepen the thoughtfulness and length of student responses, and to encourage students to ask their peers questions during a class discussion (Rowe, 1973).

The suggestions concerning divergent questions and "wait-time" can be viewed as encouraging the personal, intuitive side of the learner, as well as encouraging a synthetic information processing strategy. A divergent question allows for individual interpretation, and is oftentimes not specific to only one particular frame of reference. Also, if a problem were already presented and analyzed by the students, a divergent question, eliciting plausible hypotheses to explain observed phenomena, accompanied by "wait-time" periods of several minutes (or even hours and days), could be seen as an encouragement of the timeless nature of incubatory thought.

Creative Teaching. When the program developers speak of creative teaching in the handbook, they come the closest to making explicit suggestions for the encouragement of the generation component. The handbook states that a major characteristic of the creative teacher is the ability to set up a classroom atmosphere which seeks and rewards originality. Originality in the handbook is defined as a unique idea for the student, and not necessarily an original idea within the body of scientific knowledge. As Karplus and Their (1965), the principal program developers, state: "Each child, however, acquires competence in his own way. If all were forced to exhibit the same accomplishments at many intermediate stages, their overall progress would be severely restricted" (p. 74).

It is also assumed that the formulative act of generating hypotheses in scientific inquiries is original for the student in the same way as expressed by the SCIS developers. The handbook even uses the same language in describing creativity that is employed when describing the synthetic and metaphorical characteristics of incubatory thought. "Creativity can be sparked by setting up situations that allow children to view phenomena from *different frames of reference* [italics mine]" (*SCIS Teacher's Handbook*, 1974, p. 28).

The SCIS Teacher's Guide:

The suggestions given in the *SCIS Teacher's Handbook* about the role of the teacher in implementing the learning cycle can be viewed as *general* guidelines for conducting scientific inquiry. The characteristics of the environment suggested to the teacher are designed by the developers to facilitate scientific inquiry and, therefore, to a degree may also encourage the generation component. It is necessary to look deeper at the *specific* teaching suggestions, offered by the *Teacher's Guide* during the course of an inquiry, to determine further the quality of this encouragement. In order to accomplish this analysis, the previous illustration of the learning cycle, which examined the scientific model concept, is again reviewed in light of the specific suggestions given to the teacher during its implementation.

The Teacher's Role in Exploration. In the exploration stage the teacher demonstrates the electric circuit puzzle, and asks the students to discover how the foil which is visible through the holes is laid out inside the card. In terms of the Wallas model, this act of presenting a problematic situation to the class can be viewed as the creation of the motivational energy (or cognitive dissonance) to conduct an inquiry. It is assumed that cognitive dissonance is created for each student. The teacher is then directed by the *Models* unit *Teacher's Guide* (1971) to carry out student suggestions, which test for complete circuits. The guide also suggests that the students record their observations. Both of these activities can be viewed as the preparation stage of inquiry. The *Models* unit *Teacher's Guide* (1971) then states: "After you have completed the tests, invite the children to answer your original question about the foil arrangement and ask for supporting evidence" (p. 48). This statement can be interpreted to mean that the students should now generate plausible hypotheses which explain their observations. Because of the immediacy in *time* between the preparation stage and the request by the teacher for plausible hypotheses, there is little question that in this beginning phase of the exploration stage, the generation component receives a minimal amount of encouragement.

The major portion of this stage, however, does provide the student with more incubatory time. The students are given a puzzle to create and then are asked to discover the arrangements of puzzles created by others. The guide suggests that the teacher "encourage the children to test and exchange puzzles as long as they are interested and time permits. At the end of the class period, you may wish to store the puzzles on the science table for further investigation" (p. 49).

There are two critical factors that are different in this series of experiences than in the previous series. First, the students can manipulate the puzzle for themselves; this serves to enhance the personal dimension of the learner necessary for intuitive thought about a problem. Second, the time factor is greatly increased, especially by the suggestion that the puzzles can be put aside on a table for later investigation.

Both of these elements in turn foster the incubatory thought in this phase of the exploration stage to a greater degree than in the opening series of experiences, where the teacher demonstrated the puzzle. In addition, the students during this sequence have a greater opportunity to formulate predictions based on their hypotheses, and to test these predictions. In terms of the Wallas model, this portion of the exploration stage also encourages the verification stage of inquiry.

Teacher's Role in Invention. The invention stage of the SCIS learning cycle begins with a demonstration of the electric circuit puzzle that is very similar to the beginning activity of the exploration stage. The same problem is posed and the same procedure is followed. Even though the guide implies that the teacher should take more time in this demonstration than in the previous one, this experience still leaves little time for incubation. The Models unit Teacher's Guide (1971) does imply, however, that hypotheses are generated through imagery by stating: "Your pupils should imagine how the puzzles might have been built, basing their opinions on the results they observed" (p. 52).

Teacher's Role in Discovery. After the term "scientific model" is introduced, another problematic situation is introduced through the "push-pull" system. This is another teacher demonstration, and it marks the beginning of the discovery phase of the learning cycle. The instructor presents this system (which is an enclosed box with two rods extending from it), and after demonstrating its characteristics, requests that the students "think up a model for the 'push-pull' system" (p. 53). The guide does not suggest any time allowance between observations and the generation of the model, nor are there specific hypothesis generating strategies (i.e., guided imagery, deferred judgment, and meditation, etc.) included at this interphase between the preparation and the incubation stages. It can be concluded that this series of activities involving the "push-pull" system does little to encourage the generation component.

One aspect of the SCIS curriculum which hasn't been mentioned are the "Optional Activities" included at the end of most chapters. With regard to the "push-pull" system, there is an optional activity the teacher may employ which does encourage more incubation time. This activity suggests that the system be set aside so that students may explore it further.

Another discovery stage activity considers the inquiry boxes. In this sequence of activities, the teacher asks the students to formulate models which describe the shape of the obstructions in each of the different colored boxes. This experience can be divided into four phases, which correspond quite well to the Wallas model of scientific inquiry. In the first phase, the students are confronted with a problematic situation. The teacher distributes a set of four boxes to each team of students, and asks them to speculate about the contents of each box. The next sequence of experiences consists of student exploration of the inquiry boxes. It is suggested by the Models unit Teacher's Guide that students be allowed only a brief time (10 minutes or less) for this exploration. This phase can be seen to correspond to the preparation stage of inquiry.

In the third phase, the students are requested to generate a model that explains their observations. Each team's models are shared with the rest of the class, to provide each student with plausible hypotheses other than their own. The fourth phase of this activity can be viewed as corresponding to the verification stage. It is suggested that the teacher "urge the children to modify or extend the models after they have made more observations" (p. 58). In addition to these inquiry-box activities, there is an "Optional Activity" that allows the students even more time to explore the boxes.

Conclusions About SCIS

Based on the information presented, it is possible to draw some conclusions about the encouragement of the SCIS curriculum of the hypothesis generating component of scientific inquiry. Without question, the shift in emphasis by the program developers toward the inquiry part of the definition of scientific literacy promotes both the generation and testing components to a greater degree than those science programs which focus on the knowledge part of the definition. It is viewed, however, that much of this emphasis has been directed toward the presentation of problematic situations and toward the testing of possible explanations, without giving enough emphasis to the generation of these explanations. Within the scope of all of the approximately 250 lessons in the program, the primary activities of the student revolve around the acts of verification, without giving ample time to the generation of explanations that are being tested. The question may arise: How much time should a science program devote to these formulative acts? This is predominately an empirical question and no research in this area has been conducted. A logical answer to this question is that the amount of time necessary to formulate a hypothesis will vary with each student and within each inquiry. What is examined in this discussion is whether or not time is given at all during student activities, in the form of teacher directions and/or instructional methods, which foster the information processing strategies of the right hemisphere. In this regard the SCIS program is inconsistent when viewed in relation to the five characteristics of incubatory thought.

SCIS and Synthetic Thinking. The SCIS program encourages synthetic thinking in a broad sense by presenting students with an expanded conceptual framework. The program proceeds to sequence this information, however, into a linear format which may limit the degree of this encouragement. Within the learning cycle, the exploration stage can be viewed as an effort to foster wholistic thinking. With only general directions given to students by the teacher, the opportunity is present for them to bring their previous reference frames to bear on the problem under consideration. Suggestions in the handbook to the teacher to ask more divergent questions and to increase the "wait-time" factor can be viewed as an encouragement of synthetic thinking. Further suggestions in the handbook for ways to extend various SCIS activities, both to outdoor settings and to other disciplines, would also nourish synthetic thought about a problem.

SCIS and Imaginary and Metaphorical Thinking. The fact that hypotheses can be formulated through imagery and metaphorical connection is not specifically addressed by the program developers. There is little evidence of an encouragement by the teacher to request students to think about their problems in a metaphorical or imaginary way. There is no evidence in the learning cycle of specific instructional strategies which facilitate these characteristics of incubatory thought. The program does, however, request student feedback on some activities in an image form, through drawings in their manuals. This mode of feedback can be seen as an encouragement of imaginary thinking about a problem under consideration. It can be inferred that by confronting students with a problematic situation, by giving them concrete materials in individual and small group arrangements, and by asking them divergent questions with an increased amount of "wait-time", imaginary and metaphorical thinking will occur. In this sense the SCIS program allows for this dimension in a very indirect and implicit manner.

SCIS and Timelessness. Within most of the SCIS activities in the learning cycle, there are specific time constraints suggested in the teacher's guide, although a teacher may choose to ignore these and proceed to offer more time for incubatory thought. The element of time is only mentioned under the concept "wait-time," but the increase of this factor that is discussed in the handbook is only a matter of one or two minutes. There is no statement in either the SCIS Teacher's Handbook or the Teacher's Guides that alludes to the importance of providing each student with enough time to formulate hypotheses. In the learning cycle, the time allowances vary and are inconsistent. The discovery phase lessons provide the most incubatory time, whereas the invention phase activities provide the least amount of time for incubation. The "Optional Activities" at the end of most chapters in each unit suggest that the students be allowed more time with the problem under consideration. This can be viewed as an encouragement of the timeless quality of incubatory thought.

SCIS and Intuitiveness. There are several ways in which intuitive thinking is encouraged. The organization of the SCIS classroom, which emphasizes individual and small group activities with concrete materials, creates the opportunity for each student to intuitively consider his/her problem. This is especially evident in the exploration and discovery stages of the learning cycle. The use of divergent questioning strategies and an increase in the "wait-time" factor serves to enhance the personal and subjective nature of intuitive thought. Moreover, suggestions in the handbook to reward individual originality enhances this dimension. Also, an atmosphere of acceptance is created by all of the above mentioned factors. This results in the encouragement of the psychological freedom and safety necessary for each student to approach a problem with an intuitive mind set.

In conclusion, the Science Curriculum Improvement Study does promote inquiry experiences for each student. Its greatest weakness is that it does not clearly delineate the important difference between the type of thinking required to generate a hypothesis and the type required to test it. Without this clarification, the two-component process of inquiry becomes merged and blurred together, leaving the teacher without directions for appropriate strategies and conditions that correspond to each component. This point is especially relevant when considering the generation component. Because of its subjective and oftentimes unobservable characteristics, this operation has only recently (e.g., Medawar, 1967) become distinguishable as a complementary partner to the testing component. The SCIS curriculum, when examined in relation to the characteristics of incubatory thought, does encourage the generation component of scientific inquiry. This encouragement proceeds in an implicit, indirect, and inconsistent manner. With respect to the third hypothesis of this study, it is viewed that this examination and evaluation leads to a discovery of the extent to which SCIS encourages the generation component. Based on this conclusion, this hypothesis is accepted in relation to SCIS.

Essence I

Background and Goals of the Program

The second program that is explored in light of the subquestions of this discussion is the Essence I program. This program, originally named the Environmental Studies project, was funded in 1970 by the National Science Foundation, under the sponsorship of the American Geological Institute. The materials, developed in four phases, are designed to be applicable in all grade levels. "In classroom testing, these materials were used in every discipline at every grade level from elementary school through college" (Essence Booklet, 1971, p. 3). This focus is different from that of the SCIS program, which is designed to be used with elementary school students.

In contrast with the intent of the SCIS program developers to promote the inquiry process in a general manner, the developers of Essence were guided by a more specific goal. It is the facilitation of the hypothesis generating component of inquiry. This goal not only implies an awareness by these developers that there are two complementary components of scientific inquiry, but also implies an awareness that the generation component is underemphasized in the teaching of science. The creators of Essence I acknowledged that in the 1960's the development of science educational programs shifted its direction positively toward the inquiry aspect of scientific literacy. This effort, however, was perceived to be incomplete, since these "new" curricula produced materials which focus primarily on the testing component, and "generally ignores the process of scientific invention" (Samples, 1974, p. 2). The Essence materials are an attempt toward completion. Since the hypothesis testing component proceeds through the information processing strategies of the left hemisphere, which are characterized by linear analysis, the chief function of each Essence assignment is to confront students with non-linear situations. These situations shift their thinking toward the information processing strategies of the right hemisphere. "One of the obvious effects of the Environmental Studies program is to de-emphasize the linearity found in most curricula" (Romey, 1969, p. 326).

When examining and evaluating Essence I with respect to its encouragement of the hypothesis generating component, the same format is applied that is used in the discussion of SCIS. The characteristics of incubatory thought are considered in discussions of the conceptual framework, the vehicle which presents this framework--the assignment card--and the role of the teacher in implementing the assignment card.

Conceptual Framework of Essence I

The organization of the SCIS program into broad conceptual structures is viewed as an encouragement of synthetic thinking about the domain of scientific knowledge. This framework is characterized as a multidisciplinary approach to conceptual organization. The SCIS "systems" concept, which is considered in physical, chemical, and biological settings, illustrates this multidisciplinary crossing of traditional subject matter areas. The Essence I program is also organized into wholistic concepts. Examples of broad concepts under consideration include: power, physical and living change, cause and effect, and environmental factors. None of the Essence I assignments require the student to focus on any one specific discipline. There is, however, a major difference in the conceptual organizations of these two programs. This difference ultimately affects the degree of wholistic thinking that is encouraged for the student.

In contrast to the multidisciplinary approach of SCIS, the Essence I developers have designed their materials in a *transdisciplinary* fashion. This approach differs on one critical dimension from the multidisciplinary format, and even from an interdisciplinary method of conceptual organization. In the transdisciplinary approach the *student* is the dominant force in making decisions about the direction a particular assignment takes. In the other two methods, the direction of a given assignment is developed in an *a priori* manner by someone other than the student. Figure 9 expresses this relationship between these three kinds of conceptual organization (*Essence Booklet*, 1971).

In order to cross disciplines according to student direction, a synthetic, non-linear information processing strategy must be employed. This is a chief characteristic of incubatory thought. This is not to imply that the other two approaches (multidisciplinary and transdisciplinary) do not foster wholistic thinking, but that the transdisciplinary approach, by giving the student more responsibility for conceptual organization, facilitates this type of thinking to a greater degree. The difference between the multidisciplinary approach of SCIS and the transdisciplinary nature of Essence I is further explicated when the linearity of the conceptual organizations of these programs is compared.

The SCIS program provides a sequential, hierarchial format which directs the introduction and degree of examination of wholistic concepts. The Essence I materials do not specify when and in what order concepts are introduced, nor do they indicate the direction in which a concept may be

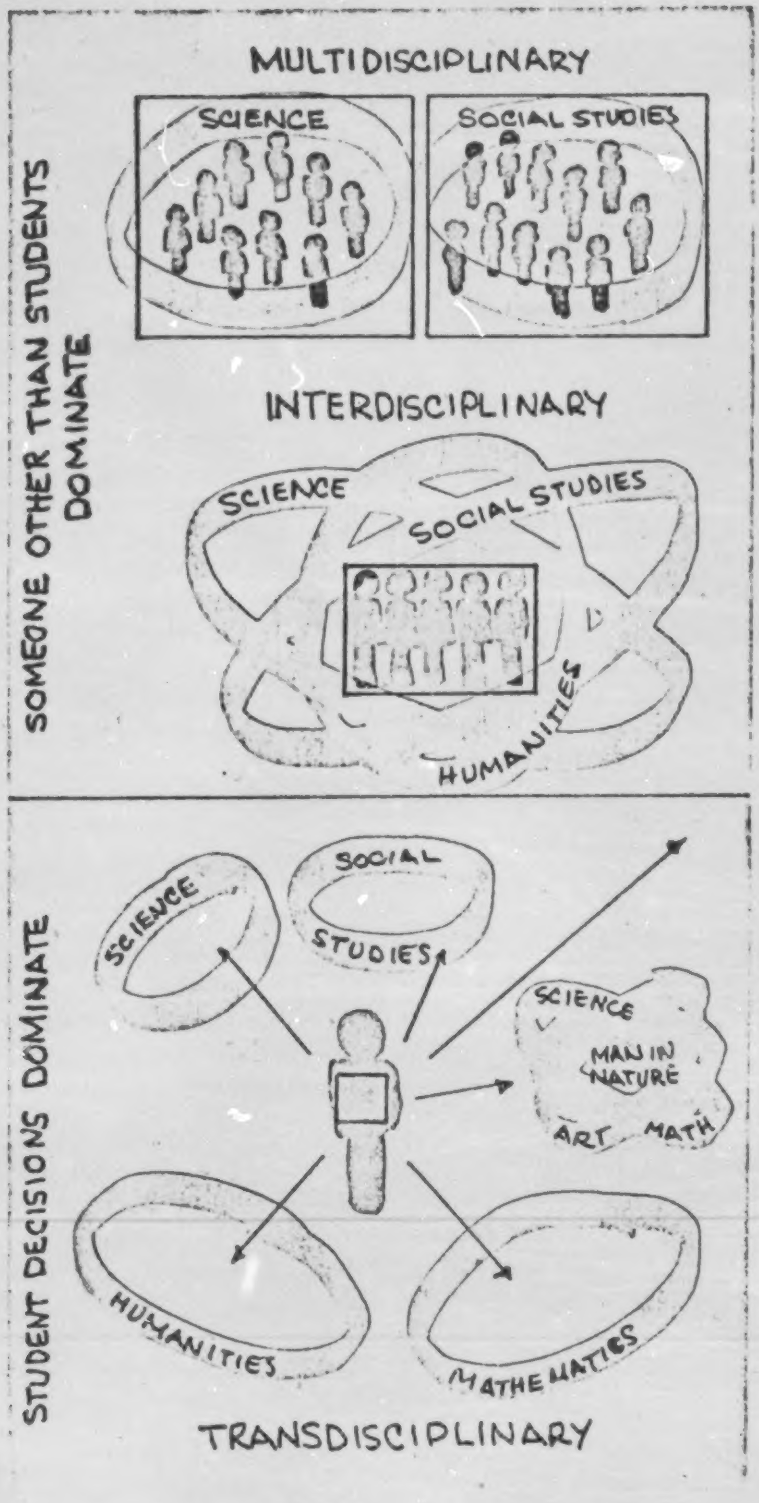

MULTIDISCIPLINARY
SCIENCE
SOCIAL STUDIES
INTERDISCIPLINARY
SCIENCE
SOCIAL STUDIES
HUMANITIES
SOMEONE OTHER THAN STUDENTS DOMINATE
SOCIAL STUDIES
SCIENCE
SCIENCE
MAN IN NATURE
ART
MATH
HUMANITIES
MATHEMATICS
STUDENT DECISIONS DOMINATE
TRANSDISCIPLINARY

Figure 9. Three Types of Conceptual Organization

examined. For instance, the "systems" concept of SCIS is introduced at the second level and at specified points throughout the other four levels. In Essence I there is an assignment for the students to "go outside and find things that represent power." The concept "power" can be presented at any grade level, at any time during the program, and can be reintroduced again at the direction of the student. There is no suggestion by the teacher to find specific kinds of power within any one discipline.

This important difference in linearity can be traced to the learning theories applied by the developers of each program. The SCIS program relies predominately on the theories of Piaget and Gagne. Each of these theorists could be classified as left-hemispherically oriented, concerned with the order, logic, and sequence of information before it is presented to a learner. The Essence I group took a decidedly different tack, and followed a more right hemispheric mode of conceptual organization: an organization which allows the learner the freedom to decide the degree of sophistication and time he/she explores and examines a concept; one which gives the learner complete responsibility for conceptual organization. Psychologists mentioned by the Essence I developers as having a philosophy of learning consistent with theirs include: Abraham Maslow, Carl Rogers, and Richard Jones.

Samples (1976) presents a right-hemispherically oriented framework of knowing with which the organization of Essence I concepts can be viewed. This framework, called the "metaphoric mind", encompasses four modes of knowing: the symbolic, the synergic-comparative, the integrative, and the inventive. These modes, in contrast to Piaget's four levels of knowing, are not hierarchially dependent on degree of complexity of concepts or on chronological order. Each operates within the individual in a simultaneous and timeless manner--one of the characteristics of incubatory thought.

The symbolic metaphoric mode "exists whenever a symbol, either abstract or visual, is substituted for some object, process, or condition" (Samples, 1976, p. 83). Some symbols used in Western societies include: trademarks, logos, and many map markings. In the Essence program there are student assignments which foster this mode of thinking. One example activity requests the student to map the flow of people in and around the school. In this assignment, a symbolic representation (a map) is substituted for the movement processes of the individuals at the school.

The synergic-comparative mode occurs "when two or more external objects, processes, or conditions are compared in such a way that both of the external components unite to become more than either one alone because of the comparison" (Samples, 1976, p. 88). The concept "synergy" describes what happens "when all of the parts of a system work together so that their effect is greater than the sum of the parts working independently" (p. 88). Some examples of this type of thinking in Western society include such comparisons as:

the Volkswagen car is like a beetle, the excretory system is like a plumbing system, and the mitochondria of a cell is like the engine of a machine. In these examples, the comparisons give each of the terms a deeper meaning than either had before a synergic, metaphoric comparison. In Essence I there are student assignments which encourage this mode of thinking. One activity requests the student to go outside and relate the following pairs of words: (a) a garbage can to a stomach, (b) a kid to a number, (c) a lifetime to a word, (d) a school to a supermarket, (e) a school to a lawn, (f) time to being hungry, and (g) love to a water fountain. In this activity comparisons are made between two objects, processes, or conditions with the intent of uniting them in a way that enhances and deepens the meaning of each.

The integrative mode exists "when the physical or psychic attributes of the person involved are extended into direct experience with objects, processes, and conditions outside themselves" (Samples, 1976, p. 92). Whereas the previous two modes do not require the student to physically identify with the concept under consideration, the integrative mode demands this contact. In the Essence I program there are assignments which facilitate this operation. One activity requests the student to go outside and find things that move and then move like they do. During this assignment the student brings his physical body into contact with the concept of movement in the environment.

The inventive mode occurs "whenever a person creates a new level of awareness of knowing as the result of self-initiated exploration of objects, processes, or conditions" (Samples, 1976, p. 97). In relation to the other modes, the inventive mode is the closest to the process of generating a hypothesis. In Essence I there are more assignments that request the student to operate along this mode than there are assignments for any of the other modes. This design is consistent with the emphasis in Essence I on the generation component of inquiry. One example of an inventive mode activity requests the students to take familiar objects from their environment, and to invent and demonstrate a new use for each of them.

In perspective, the conceptual framework of Essence I is different from the SCIS framework. While the SCIS concepts are broad based, they are directed in two linear ways: the ordering of concepts from concrete to abstract, and the ordering of concepts from simple to complex. The Essence I program employs a very different conceptual framework. Each wholistic concept is organized to facilitate one or more of the four non-linear modes of right-hemispheric thinking. As in the examination of SCIS, it is necessary to examine how the Essence I framework is presented to the student. While the SCIS program utilizes a learning cycle (of exploration, invention, and discovery) to present its conceptual framework, Essence I utilizes assignment cards.

The Essence I Assignment Card

The Essence I materials consist of over 50 assignment cards. In keeping with their non-linear goal, the program developers package each set of assignment cards in a randomized fashion, so that each teacher probably receives his/her set of cards in a unique order. Each card includes five elements (Romey, 1976). They are:

1. A pictorial or graphic metaphor and title. This element contains an image, which reflects the intent of the assignment, and a catchy one- or two-word caption.
2. The Action. The presentation of the assignment in a short statement.
3. More. A section which suggests further assignments that extend the Action element.
4. Notespace. Space on the card for the teacher and/or the student to generate more assignments.
5. Side Comments. Ideas printed around the border of the card which reflect the teacher's role in the use of the card.

An example of an Essence I assignment, which depicts the layout of these five elements, is presented in Figures 10 and 11. Figure 10 presents Side One--the pictorial or graphic image and title caption. The other side of the card presents the remaining four elements and is depicted in Figure 11.

When considering how a concept is initially presented to a student in an Essence I assignment, three of the five

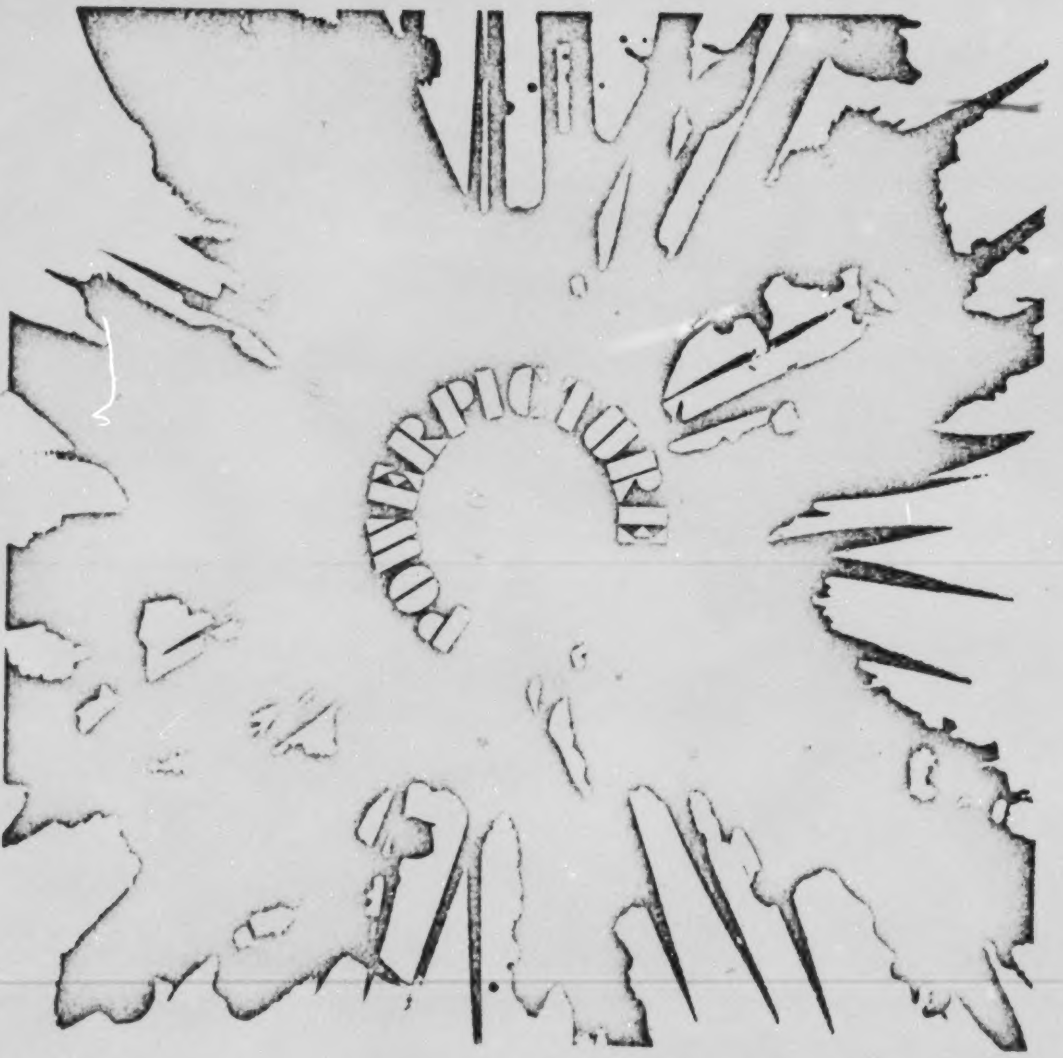
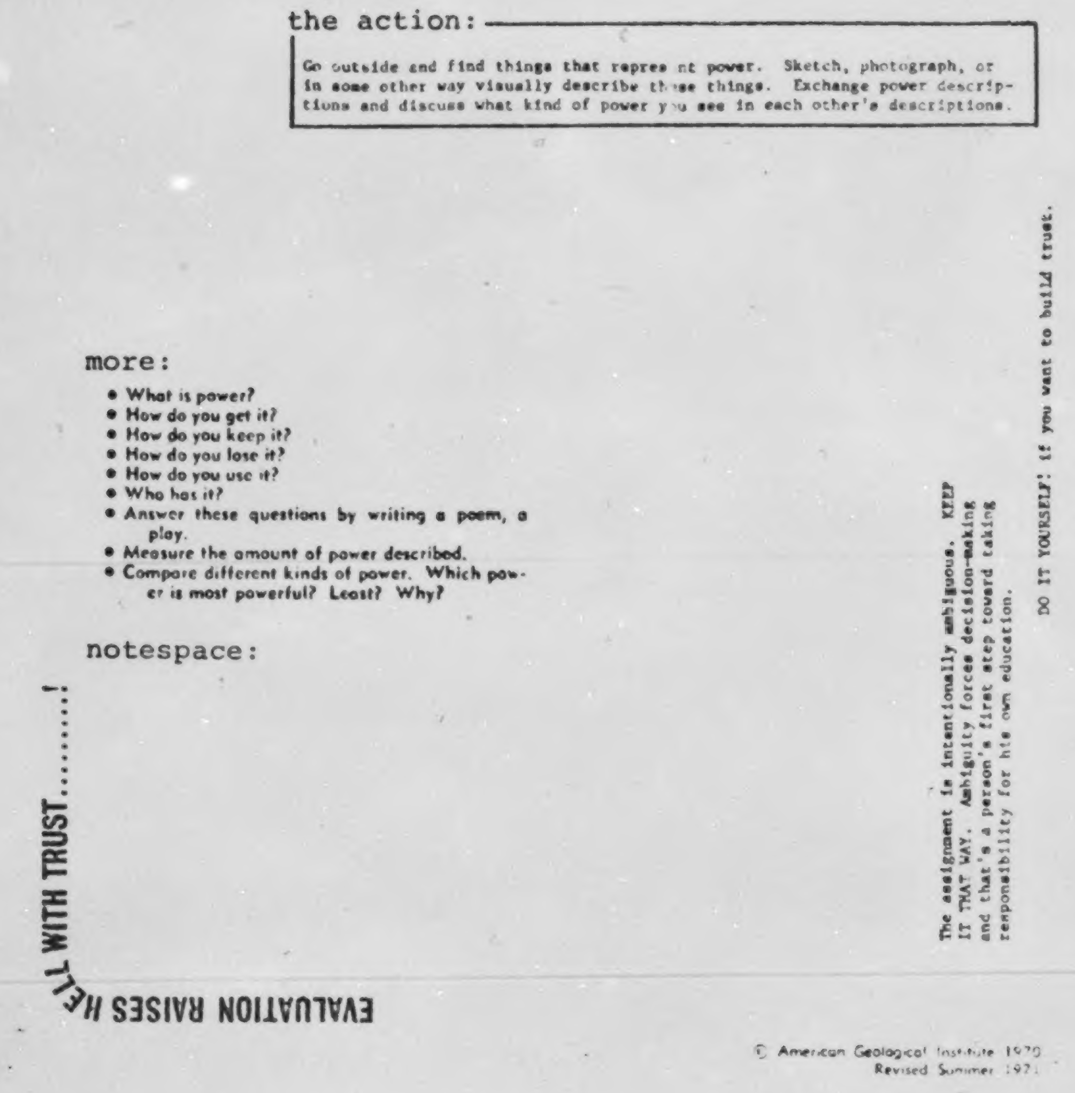

POWERPICTURE

Figure 10. An Example of an Essence I Assignment - Side One



the action:

Go outside and find things that represent power. Sketch, photograph, or in some other way visually describe these things. Exchange power descriptions and discuss what kind of power you see in each other's descriptions.

more:

- What is power?
- How do you get it?
- How do you keep it?
- How do you lose it?
- How do you use it?
- Who has it?
- Answer these questions by writing a poem, a play.
- Measure the amount of power described.
- Compare different kinds of power. Which power is most powerful? Least? Why?

notespace:

EVALUATION RAISES HELL WITH TRUST.........!

The assignment is intentionally ambiguous. KEEP IT THAT WAY. Ambiguity forces decision-making and that's a person's first step toward taking responsibility for his own education.

DO IT YOURSELF! if you want to build trust.

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Figure 11. An Example of an Essence I Assignment - Side Two

elements are pertinent. They are: (1) the picture and/or graphic image and title, (2) the "Action" element, and (3) the "More" element. The "Notespace" element is considered as a section which is useful after the concept is presented. It is therefore not considered pertinent to the initial presentation of a concept. The "Side Comment" element concerns the teacher's role in presenting the assignment, but it is considered in a subsequent discussion about the role of the teacher in implementing the Essence I program.

The Pictorial and/or Graphic Image and Title. Since hypotheses can be generated through imagery and metaphorical connection, one of the aspects of this investigation considers the encouragement of imagery and metaphorical thinking by the Essence I materials. Side One of the assignment card is an important method in which this characteristic of incubatory thought is encouraged. The students are free to view this side of the card without interpretation from others. As Romey (1976) states: "Just looking at the picture and title may be enough to suggest activities to learners and teachers" (p. 102).

The assignment card that requests the students to map the movement of people in the school possesses a double exposure photograph of a person walking down a street. It is titled "peoplepaths." Another assignment, which requests the student to take familiar objects and invent a new use for them, possesses a picture of a nail being driven into a piece of wood with the end of a soft drink bottle. It is titled "Meta 4 Three."

The Action and More Elements. The "Action" and "More" elements of the assignment card consist of short statements describing problematic situations. Since the intent of both of these elements is basically the same, they are treated together in this section. Both SCIS and Essence I are consistent with the Wallas model of inquiry, because they begin the inquiry process by confronting students with problematic situations. As mentioned previously, the transdisciplinary framework of Essence I does not create a linear order in which problems are given to students. The students may choose any of the assignment cards at any time during their exposure to the program. Also inherent in this choice is the freedom for students to make decisions as to the extent each assignment is considered, and as to the direction the inquiry takes them.

The "More" section can be viewed as a method which greatly extends the number of problematic situations that can be chosen by students to investigate. Also, the availability of the "Notespace" section encourages the inclusion of new problematic situations. In this way the student can extend the number of problematic situations. Both the "More" and "Notespace" sections serve to increase the number of possible problems in the program to an infinite range. Table 7 presents several examples of Essence I card titles, "Action" statements, and "More" statements.

Table 7

Examples of Essence I Assignment Card Titles, "Action" Statements, and "More" Statements

CARD TITLE	"ACTION" LINE	"MORE" STATEMENTS
1. Egg Hunt	Go outside and find as many different kinds of eggs as you can and bring them back.	a) Do plants have eggs? b) Find some "eggs" of social change. c) What does it mean to be an egg?
2. Show Me a Million	Go out and find a million of something and prove it.	a) What is proof? b) Do it again at home, at school.
3. Live Change	Go outside and prove that some living thing in your environment changes.	a) Life what? b) Life why?
4. Cause and Effect	Go outside and find two things, one of which is responsible for the other.	a) Find a cause and effect relationship in which the affected thing is increased or decreased.
5. How Old?	Find the youngest and oldest thing in school or outside.	a) How is age determined? b) Describe oldness, youngness, without using those words. c) Make a collage of very old things.
6. The Happening	Go out and find positive evidence that something natural happened.	a) What are some negative, positive, and neutral aspects of each happening? b) Are man-made happenings natural?
7. Predator Prey	Go outside and find who in the community are predators and who are prey.	a) What happens when the predator and prey change places? b) Will the balance of the environment be affected if any of the predators or prey are removed?

There are three other characteristics of the "Action" and "More" elements. One is that there are no specified time limits suggested to the student or teacher for the completion of a given assignment. In either of these elements problems can be presented to students, with time allowances of hours, days, or weeks, before feedback about the assignment is requested. This flexibility is extremely important, since an essential characteristic of incubatory thought is its timelessness. Combining two reference frames is a non-linear act, which is not governed by time deadlines. This flexibility is in contrast to the SCIS program, which proceeds through specified time suggestions.

A second characteristic of the "Action" and "More" elements is that there are two different types of assignment cards. The examples of the cards, previously illustrated in Table 7, can be classified as the _content-oriented_ type. They deal with specific content areas in the domain of scientific knowledge. The other type of assignment card has not previously been discussed. These are the cards directed _specifically_ at the facilitation of incubatory thought. Some examples of action statements of this type include the following:

1. _Keep a book of your fantasies, day dreams, and night dreams_. Through this assignment, students become more attuned to the imaginary qualities of incubatory thought.

2. Find out which people manipulate other people and which people get manipulated. Through this assignment, the students can develop an awareness of how thoughts and actions of others affect them. With this awareness the students may more easily narrow their consciousness to exclude outside interferences and thereby improve their subjective, intuitive thought about a problem.
3. Find objects that don't look alike but are similar in some way. Through this assignment the students are required to think metaphorically about objects in their environment.
4. The whole environment is one gigantic system, and each person is a part of it. Find out what happens to the system when you switch on and when you switch off. Through this assignment the students are required to think synthetically about their place in the environment.

The Role of the Teacher in Essence I

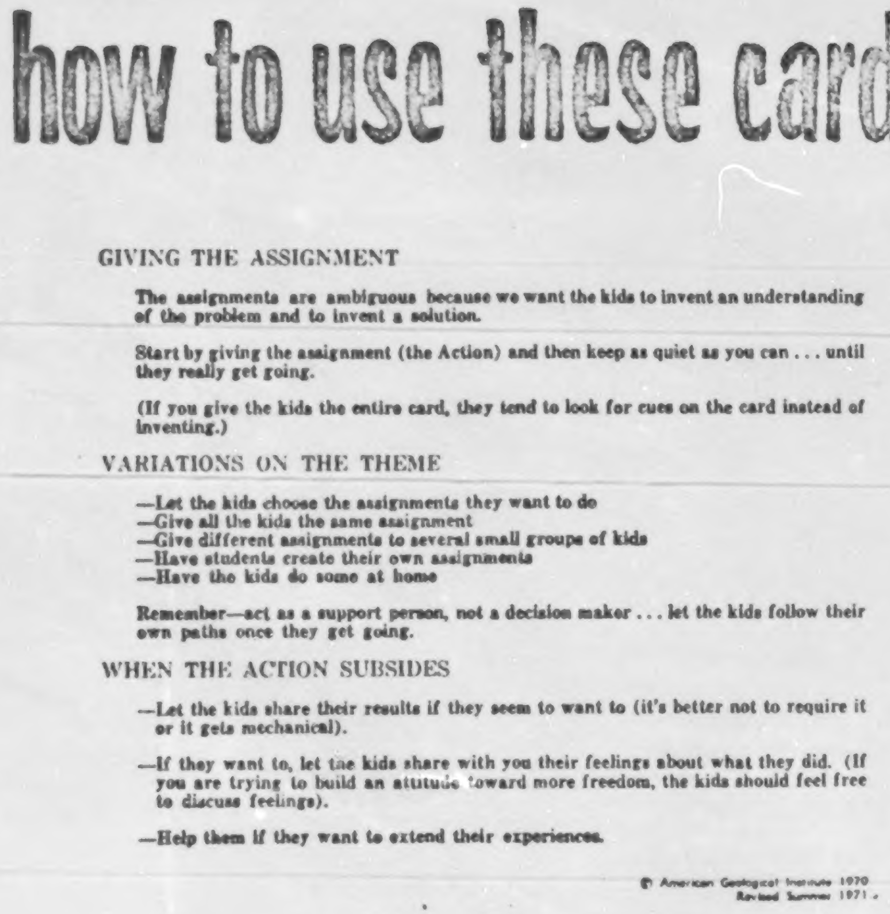
Now that the conceptual framework of Essence I and the vehicle (the assignment card) which presents this framework to the student have been considered, it is necessary to examine the teacher's role in implementing the program. In keeping with the specific goal of the developers to encourage the generation component, suggestions to the teacher are directed toward the creation of an environment which facilitates the characteristics of incubatory thought. An environment where "true inquiry takes place under non-coercive conditions where the learners can explore, fail, succeed, and learn in an atmosphere of trust and caring support" (Romey, 1972, p. 106). The Essence I developers provide three major methods which serve to facilitate this environment. They are (1) side comments, (2) the "How to Use These Cards" card, and (3) the Essence Booklet.

Side Comments. On each assignment card there are comments for the teacher which reflect the characteristics of an environment conducive to incubatory thought. Some example comments include: (a) "Evaluation raises hell with trust," (b) "Why is a dangerous question . . . . Accept responsibility for it," and (c) "What you are speaks so loudly, kids cannot hear what you are saying." In general, these statements stress "ideas such as trusting, accepting, and caring for the student as people, having the teacher be a model of openness, getting rid of comparative or coercive evaluation in the group" (Romey, 1976, p. 103). These comments advocate a learning environment that Rogers (1961) describes as possessing psychological freedom and safety for each student. In order to establish this environment, the teacher is given more specific suggestions in the "How to Use These Cards" card.

The "How to Use These Cards" Card. The "How to Use These Cards" card is designed for the teacher as a quick, easy reference about the application of Essence I assignments. It has three major parts which include: (1) "Giving the Assignment," (2) "Variations on the Theme," and (3) "When the Action Subsides." Figure 12 presents this card.

Upon examination, it is clear how this card can serve as a vehicle for the teacher in creating an environment conducive for the hypothesis generating component. In the first section, there is a suggestion that the instructor remain quiet and unobtrusive when giving the assignments to the students. This action removes initial input by an authority figure. It eliminates an immediate source of evaluation for the student, which may interfere with the private, subjective nature of intuitive thought. In the second section, there are several ways suggested to the teacher for implementing any given assignment. This acknowledgement is consistent with the variety of formats through which incubation can occur. In the third section, all of the suggestions contain the phrase "if they want to." This statement underscores a freedom of choice given to the student while working on an Essence I assignment. This freedom is necessary for a learning environment which fosters intuitive thinking. The general atmosphere for learning, advocated by the "How to Use These Cards" card, can be summed up in a song by The Moody Blues (from the album To Our Children's Children's Children, 1969):

> There's lots of room for doing
> The things you've always been denied,
> So look, and gather all you want to,
> There's no one here to stop you trying.



how to use these cards

GIVING THE ASSIGNMENT

The assignments are ambiguous because we want the kids to invent an understanding of the problem and to invent a solution.

Start by giving the assignment (the Action) and then keep as quiet as you can . . . until they really get going.

(If you give the kids the entire card, they tend to look for cues on the card instead of inventing.)

VARIATIONS ON THE THEME

—Let the kids choose the assignments they want to do
—Give all the kids the same assignment
—Give different assignments to several small groups of kids
—Have students create their own assignments
—Have the kids do some at home

Remember—act as a support person, not a decision maker . . . let the kids follow their own paths once they get going.

WHEN THE ACTION SUBSIDES

—Let the kids share their results if they seem to want to (it's better not to require it or it gets mechanical).

—If they want to, let the kids share with you their feelings about what they did. (If you are trying to build an attitude toward more freedom, the kids should feel free to discuss feelings).

—Help them if they want to extend their experiences.

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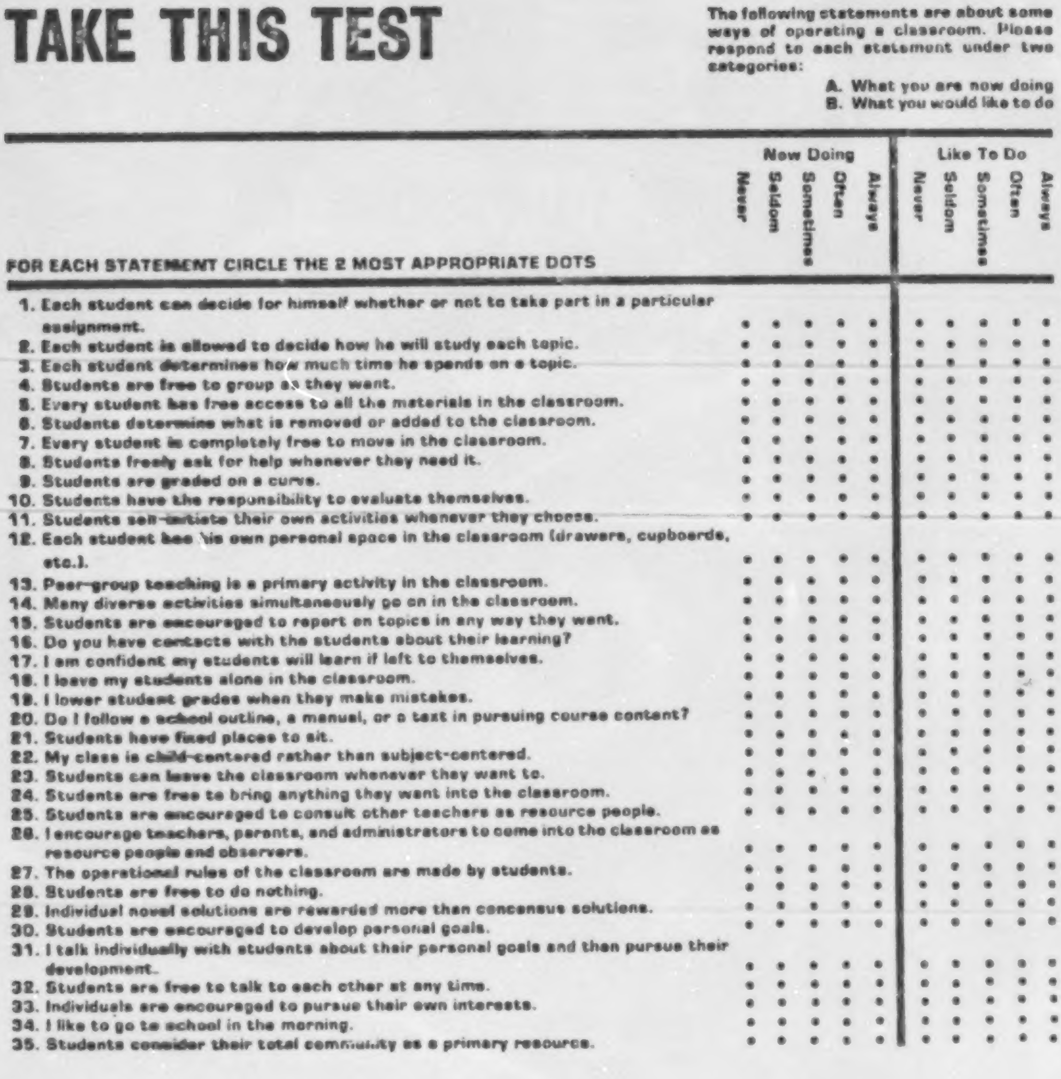
Figure 12. The "How to Use These Cards" Card (from Essence Booklet, 1971)

The Essence Booklet. The Essence Booklet (1971) is designed for the teacher and accompanies each set of assignment cards. Included in this booklet is information about the program. The developers, however, are quick to point out in the opening paragraph that their booklet is not a traditional teacher's guide. "This is not a teacher's guide. It is a collection of ideas we had about things we have done. It is not a recipe. You are teachers . . . not cooks. None of us know your students as well as you do. If anything you should be telling us about them" (Essence Booklet, 1971, p. 1).

This booklet contains discussions about the characteristics of an environment which facilitates incubatory thought. Some of these include: free communication, self-initiated activity, playfulness, few rules, self-discipline, free choice of involvement, free access to all materials, and an atmosphere of invention. An important aspect of the Essence Booklet (1971) is its request that the teacher initially assess his/her classroom environment. One way this is accomplished is to ask the teacher to take a test. Figure 13 presents this test. Through this experience, the instructor may gain a valuable perspective about the effects of the environment he/she creates on the facilitation of the generation component of inquiry. Many of these statements involve the question of student choice in the learning environment. For example, the statement "Each student determines how much time he spends on a topic" is directly related to the timeless nature of the generation component.



TAKE THIS TEST

The following statements are about some ways of operating a classroom. Please respond to each statement under two categories:

A. What you are now doing
B. What you would like to do

FOR EACH STATEMENT CIRCLE THE 2 MOST APPROPRIATE DOTS	Now Doing					Like To Do				
	Never	Seldom	Sometimes	Often	Always	Never	Seldom	Sometimes	Often	Always
1. Each student can decide for himself whether or not to take part in a particular assignment.	•	•	•	•	•	•	•	•	•	•
2. Each student is allowed to decide how he will study each topic.	•	•	•	•	•	•	•	•	•	•
3. Each student determines how much time he spends on a topic.	•	•	•	•	•	•	•	•	•	•
4. Students are free to group as they want.	•	•	•	•	•	•	•	•	•	•
5. Every student has free access to all the materials in the classroom.	•	•	•	•	•	•	•	•	•	•
6. Students determine what is removed or added to the classroom.	•	•	•	•	•	•	•	•	•	•
7. Every student is completely free to move in the classroom.	•	•	•	•	•	•	•	•	•	•
8. Students freely ask for help whenever they need it.	•	•	•	•	•	•	•	•	•	•
9. Students are graded on a curve.	•	•	•	•	•	•	•	•	•	•
10. Students have the responsibility to evaluate themselves.	•	•	•	•	•	•	•	•	•	•
11. Students self-initiate their own activities whenever they choose.	•	•	•	•	•	•	•	•	•	•
12. Each student has his own personal space in the classroom (drawers, cupboards, etc.).	•	•	•	•	•	•	•	•	•	•
13. Peer-group teaching is a primary activity in the classroom.	•	•	•	•	•	•	•	•	•	•
14. Many diverse activities simultaneously go on in the classroom.	•	•	•	•	•	•	•	•	•	•
15. Students are encouraged to report on topics in any way they want.	•	•	•	•	•	•	•	•	•	•
16. Do you have contacts with the students about their learning?	•	•	•	•	•	•	•	•	•	•
17. I am confident my students will learn if left to themselves.	•	•	•	•	•	•	•	•	•	•
18. I leave my students alone in the classroom.	•	•	•	•	•	•	•	•	•	•
19. I lower student grades when they make mistakes.	•	•	•	•	•	•	•	•	•	•
20. Do I follow a school outline, a manual, or a text in pursuing course content?	•	•	•	•	•	•	•	•	•	•
21. Students have fixed places to sit.	•	•	•	•	•	•	•	•	•	•
22. My class is child-centered rather than subject-centered.	•	•	•	•	•	•	•	•	•	•
23. Students can leave the classroom whenever they want to.	•	•	•	•	•	•	•	•	•	•
24. Students are free to bring anything they want into the classroom.	•	•	•	•	•	•	•	•	•	•
25. Students are encouraged to consult other teachers as resource people.	•	•	•	•	•	•	•	•	•	•
26. I encourage teachers, parents, and administrators to come into the classroom as resource people and observers.	•	•	•	•	•	•	•	•	•	•
27. The operational rules of the classroom are made by students.	•	•	•	•	•	•	•	•	•	•
28. Students are free to do nothing.	•	•	•	•	•	•	•	•	•	•
29. Individual novel solutions are rewarded more than consensus solutions.	•	•	•	•	•	•	•	•	•	•
30. Students are encouraged to develop personal goals.	•	•	•	•	•	•	•	•	•	•
31. I talk individually with students about their personal goals and then pursue their development.	•	•	•	•	•	•	•	•	•	•
32. Students are free to talk to each other at any time.	•	•	•	•	•	•	•	•	•	•
33. Individuals are encouraged to pursue their own interests.	•	•	•	•	•	•	•	•	•	•
34. I like to go to school in the morning.	•	•	•	•	•	•	•	•	•	•
35. Students consider their total community as a primary resource.	•	•	•	•	•	•	•	•	•	•

Figure 13. "Take This Test" (from Essence Booklet, 1971)

In general the statements on this assessment instrument provide an opportunity for the teacher to discover the qualities of the instructional environment which are most conducive to the facilitation of the characteristics of incubatory thought.

As alluded to previously, in order for the students to operate with an intuitive attitude toward problematic situations, the teacher must serve as a model for this behavior. The Essence Booklet (1971) contains specific activities for teachers to facilitate an awareness of their own intuitive thought processes. The assumption made by the developers is that in order to create an environment conducive to hypothesis generation, the teacher must strive toward internalizing and valuing the characteristics of this component in his/her lifestyle. Some of these activities include the following:

1. For one week, check the source of each emotion you feel. This activity is intended to bring the teacher closer to his/her emotions, since the process of hypothesis generation is very often an emotional experience.
2. Set aside at least one period during the day or week when, with your class, you do something that you enjoy doing for yourself. This activity allows the students to see the teacher as a model of an intrinsically motivated and rewarded person.

Conclusions about Essence I

Based on the information considered in this discussion, it is possible to reach some conclusions about the extent to which the Essence I program encourages the hypothesis generating component of inquiry. In general, it is important to underscore the fact that it is a specific intent of the program developers to encourage this component. This intent differs from the broad goal of the SCIS developers to encourage inquiry in a general manner. Because of this difference, the evidence presented in each of the following sections can be characterized as more explicit and direct, and as requiring fewer assumptions than in the evaluation of SCIS.

Essence I and Synthetic Thinking. There are several ways in which synthetic thinking is encouraged for the student. It is stated as a major goal of the program to emphasize synthetic, non-linear thinking (Romey, 1976). This explicit purpose is translated and applied to the transdisciplinary conceptual framework. The concepts that are considered in Essence I are broad-based and are not restricted to any specific discipline. Also, this framework is organized in a non-linear manner. Concepts are not sequentially or hierarchially arranged according to degree of complexity, or to chronological order.

This goal is also transferred to the design of the assignment card. In neither the "Action" or "More" elements are there directions which would limit a student to one reference frame. The "Notespace" element encourages synthetic thinking by providing the student with the opportunity to expand his present inquiry into other directions. Also, the kind of problem presented in the "Action" and "More" sections do not have a standard method of solution known to the teacher. When the teacher knows the hypothesis which explains a problem, and has materials set aside to test this hypothesis, the student may limit his thinking about a problem in a linear way, toward the hypothesis and solution known in advance by an instructor.

With respect to the role of the teacher, there are suggestions in the "Side Comments," the "How to Use These Cards" card, and the Essence Booklet (1971) which reflect the synthetic manner in which hypotheses are generated.

Essence I and Imaginary and Metaphorical Thinking. The fact that some hypotheses are formulated through imaginary and metaphorical thinking is explicitly considered by the Essence I developers. There are four major ways in which these characteristics of incubatory thought are translated for the student during inquiries. The first method is the inclusion of a picture or drawing and a metaphorical caption with each assignment. By allowing the student to view this side of the card, imaginary and metaphorical thought about the problem is fostered.

The second and third methods relate to the two types of assignment cards present in the Essence materials. Of those which are designed specifically for a content area, there are assignments that promote either the symbolic mode of thinking or the synergic comparative mode. In these assignments the student is required to process information through imagery or metaphorical connection. Of those which are not content oriented, there are assignments which facilitate imagery or metaphorical thinking. One example previously mentioned is a request for the student to keep a record of his imaginary thoughts that occur in either fantasy, day dreams, or night dreams.

The final way in which Essence I encourages these characteristics of incubatory thought relates to the feedback requested of a student after consideration of an assignment. In most cards the students are requested to describe their thinking about a problematic situation through a photograph, poster, or drawing. This feedback mode is best performed by the right hemisphere, which specializes in processing visuo-spatial information (Levy, 1974). Also, there are feedback requests which require metaphorical thinking.

Essence I and Timelessness. Incubatory thought has a timeless quality. This characteristic is exemplified in the case study description of the inquiries of A. R. Wallace (1905). During incubation, he put together two reference frames which were separated by a twelve-year interval. The creators of Essence I are aware of this quality. The conceptual framework is not designed in a linear, time-bound fashion but is designed according to the simultaneous, right-hemispheric modes of thinking (Samples, 1976). There are no specific time restraints suggested on any assignment card. The student may engage in an inquiry as long as he/she is motivated to do so.

Essence I and Intuitiveness. The intuitive act of generating a hypothesis is a highly personal and subjective experience (Rogers, 1961; Medawar, 1967). The Essence I program promotes this dimension of scientific inquiry. Evidence for this encouragement can be seen in the conceptual framework, the assignment card, and in the role of the teacher.

The transdisciplinary conceptual framework is organized to allow the students the freedom to choose which assignments they consider. This design is based on a learning theory which posits that the ultimate organization of knowledge is a subjective and personal act (Maslow, 1971). A major advantage of placing this emphasis on the student's ability to organize information is that it encourages the opportunity for intuitive thought. This type of thinking requires the freedom for an individual to sift and select from different frames of reference.

This freedom is also present within the structure of the assignment card. When including the "Action," "More," and "Notespace" elements, the number of problematic situations a student may choose from approaches an infinite range. It is assumed by the program developers that the students apply their intuitive thought processes in making their choice of problems to consider.

In conjunction with the elements of the assignment card, the teacher's role is also critical in fostering intuitive thought. The "How to Use These Cards" card provides suggestions which create and foster the student's freedom to select problems. For instance, one of the suggestions on this card is to let the students decide which, if any, of the "More" statements they will consider. Furthermore, there are suggestions to the teacher which allude to the environmental classroom conditions necessary for an encouragement of the subjective, personal nature of intuitive thinking. A major emphasis of these suggestions is toward the removal of external sources of evaluation. Such "Side Comment" statements as "Why is a dangerous question . . . . Accept responsibility for it" illustrate this intent. It is assumed by the Essence I creators that an evaluative atmosphere limits the students' freedom to think intuitively about a problematic situation.

In conclusion, the Essence I curriculum does promote the characteristics of incubatory thought and, therefore, it encourages the hypothesis generating component of scientific inquiry. This encouragement is directly stated in the goals of the program, and it is in evidence in the conceptual framework, the assignment card, and in the teacher's role. With respect to the third hypothesis of this study, it is suggested that this examination and evaluation leads to a discovery of the extent to which Essence I encourages the generation component. Based on this conclusion, this hypothesis is accepted in relation to Essence I.

Chapter V

Summary and Conclusions

There were two major problems of this study. The first was to identify the characteristics of the hypothesis generating component of scientific inquiry. The second was to apply these characteristics to an instructional strategy for science teaching, and to current science educational curricula. From these problems, three hypotheses were investigated.

Hypothesis One - The characteristics of the hypothesis generating component of scientific inquiry can be identified.

Scientific inquiry was defined as a two-component problem solving process. These components are hypothesis generation and hypothesis testing. Hypothesis generation was defined as the operation, arising from a problematic situation, whereby a tentative, plausible explanation of the problem is created. Hypothesis testing was defined as the operation of deducing logical prediction(s) from a hypothetical explanation, and inducing empirical data to correlate the prediction(s) with reality. Both of these components interact in a complementary fashion. Neither process can be subsumed by the other, nor can either be considered as independent of the other.

A primary assumption of this study was that in the teaching of science (which reflects the practice of science), there is presently an overemphasis on the testing component at the expense of its complementary partner--hypothesis generation. A major reason for this imbalance is that the characteristics of the testing component were _already_ in an identifiable form, which could be translated to science teaching. These are the qualities inherent in the processes of induction and deduction. The characteristics of the generation component had not been clearly identified. These characteristics were derived from two sources of information.

The first source which was utilized encompassed recent neurophysiological and psychological investigations, concerning the information processing strategies characteristic of each cerebral hemisphere of the human brain. The second source was an examination of the Wallas model of scientific inquiry, a model derived from case-study reports of scientific investigations. It possesses four stages which are: (a) preparation, (b) incubation, (c) illumination, and (d) verification. From these sources, it was demonstrated that the mental acts of the generation component of scientific inquiry are performed by the right cerebral hemisphere of the brain. It was also concluded that these formulative acts occur during the incubation and illumination stages of scientific inquiry. When an investigator is in the process of generating plausible hypotheses relevant to a problematic situation, his/her thinking has six characteristics.

Hypothesis generative thought is:

1. Synthetic
2. Imaginative
3. Timeless
4. Intuitive
5. Metaphorical
6. Sudden

The second and third hypotheses which were investigated in this study made applications of these characteristics to the teaching of science. It was suggested, however, that since illuminatory thought, which is characterized by its suddenness, is a process which is totally dependent upon the occurrence of incubatory thought, the applications that were to be made should concentrate on the five characteristics of incubation.

Hypothesis Two - Guided imagery is an instructional strategy for science teaching, which fosters the characteristics of the hypothesis generating component.

Guided imagery was defined as a teaching method which leads imagery construction in a specific or general direction. The three major areas of this strategy which were examined included: (a) the definition and assumptions of guided imagery, (b) the characteristics of guided imagery, and (c) the applicability of guided imagery to science teaching. It was demonstrated that this strategy satisfies the characteristics of incubatory thinking. It was concluded that when a student is exposed to this strategy, his/her thinking is synthetic, imaginary, timeless, intuitive, and metaphorical. Also, it was concluded that this instructional method is in a form which is applicable to teaching of science, and that it could be used to foster incubation during the course of scientific inquiries.

Hypothesis Three - The Science Curriculum Improvement Study and Essence I program can be examined and evaluated to discover the extent to which each encourages the characteristics of the generation component.

The third hypothesis, also an application of the characteristics of incubatory thought, differed from the second hypothesis along a time dimension. Instead of identifying an instructional strategy which could be used in the educational process, two presently used science educational curricula were examined for their encouragement of incubatory thinking. The Science Curriculum Improvement Study (SCIS) and the Essence I program were selected for examination. Both of these programs were viewed as representative of an emphasis in curriculum development toward inquiry-oriented experiences for each student. This is in contrast to science programs which emphasize the presentation of scientific knowledge for each student. Each of these programs were investigated with respect to the five characteristics of incubatory thought (synthetic, imaginary, timeless, intuitive, and metaphorical). This investigation considered the following areas of each curriculum: (a) background and goals, (b) conceptual framework, (c) methodology, and (d) role of the teacher.

The SCIS program developers operated with the very general goal of promoting both the generating and testing components of scientific inquiry. It was concluded that this goal does not reflect a level of awareness, which clearly delineated between the information processing strategies characteristic of each component of inquiry. It was demonstrated that the SCIS program encourages incubatory thinking for each student. This encouragement was most evident for the intuitive characteristic, and least evident for the metaphorical quality of incubatory thought. Moreover, it was concluded that this lack of awareness translated into a methodology and teacher's role which encourages incubatory thinking in an indirect, implicit, and inconsistent manner. This conclusion was evidenced with respect to each characteristic.

The investigation of the Essence I program paralleled the examination of SCIS. These program developers, however, operated with the very specific goal of promoting the generating component of scientific inquiry. It was demonstrated that this goal translates into a methodology and teacher's role which encourages incubatory thinking in a direct, explicit, and consistent manner. This encouragement was evidenced with respect to each characteristic of incubatory thinking.

The Process

This dissertation is about the creative process. It deals specifically with the nature of scientific inquiry, and with the implications of this process to the teaching of science. This study reflects two overlapping levels of awareness. The first level is the most obvious. It is an awareness of the information presented in the context of these chapters. This knowledge is concrete, in the sense that it can be read, re-read, and mulled over. The second level involves my own creative process in writing about the process of scientific inquiry. It includes my own preparatory, incubatory, illuminatory, and verificatory experiences. This level can be depicted as subtle, fuzzy, and unordered. I consider it as important for you, the reader, to understand this second level of awareness as much as the first. The following is a description of how I proceeded through the various stages of inquiry, when investigating the major problem of this study.

> Initial cognitive dissonance was created within me when I was confronted with the problem of identifying the characteristics of the hypothesis generating component. This problem became clarified, in a Philosophy of Science course, when I became aware of the concept that scientific inquiry had two complementary components. From my experiences, as a student and as a teacher in science educational settings, the testing component greatly overshadowed the generation component. Upon investigation, I found supporting evidence that this condition was currently prevalent in the teaching of science. I asked myself why this condition existed and found that, in contrast to the generating component, the qualities of the testing component were clearly and explicitly identified.

A preparatory period ensued (lasting two months) in which I attempted to logically identify the characteristics of the generating component. I was basing this aspect of my investigation on the analysis of readings about the nature of scientific inquiry, the Wallas model, and on case-study reports of scientific investigations. From information contained within these sources, I induced five characteristics of the generation component. Hypothesis generation was: (a) intuitive, (b) synthetic, (c) imaginative, (d) a process that proceeds from a problematic situation, and after a fruitless analysis of it, and (e) a process that proceeds through a voluntary abstention from conscious thought on a problem.

When reflecting on these qualities, I intuitively felt dissatisfied with this list, and felt that it was not complete. I also wanted to find an empirical base to support these five characteristics. An incubation period began (lasting several weeks), and I made the metaphorical connection between two frames of reference: the preparatory frame, which included the five characteristics derived from the practice of science, and the incubatory frame, which included the "split-brain" research concerning how the mind processes its information. Incubatory states of being I experienced during this period were meditation, guided imagery (the "wise person" fantasy), informal raps with my major advisor (Jack Hassard), and long walks around my neighborhood (usually after an intense writing period). I also found that upon awakening in the morning I could incubate effectively by lying in bed for about twenty minutes in a half-awakened state.

The major insight resulting from my incubation period was that the generation component was right-hemispheric in nature. This gave me the empirical base I desired for the characteristics of incubatory thought. Also through these experiences, I expanded my list and arrived at eight characteristics of hypothesis generation. These characteristics were:

1. The hypothesis generating component arises from a problematic situation and after a fruitless analysis of it.

2. Hypothesis generation proceeds via a voluntary abstention from conscious thought on the problem.

3. Voluntary abstention is in the form of non-verbal imagery and metaphorical connection.

4. Hypothesis generation is a diffuse and non-linear process, which is not guided by explicit methodological rules.

5. Hypotheses are generated in a variety of formats, and are not restricted by the element of time.

6. Hypothesis generation is a synthetic, wholistic information processing strategy.

7. The hypothesis generation component is a process in which man contacts his intuition.

8. The hypothesis generating component is characterized by the suddenness in which the hypothesis is formulated.

Once this list was generated, a verification period ensued. This period (lasting about two months) began with questions by one of my dissertation committee members as to whether each characteristic of my list was discrete, and as to whether there is a hierarchial, linear relationship among these qualities. Further verification experiences included my attempt to apply this list to the examination of the guided imagery strategy in Chapter Three. During these attempts, I found that this list of eight characteristics could not be confirmed as it stood, and that each quality was not a discrete entity.

Cognitive dissonance was again created within me, and another preparatory period began. During this time (lasting a few weeks), I relied mostly on readings about the imagery experience, and about the Essence program. This preparatory process could be depicted as a conscious, rational effort at resolving my most recent feelings of cognitive dissonance.

A second incubatory and illuminatory period followed (lasting about three weeks). In this time frame I again utilized the "wise person" fantasy, raps with Jack, meditation, long walks, and half-awakened states of being. I arrived at several insights into this list of eight characteristics. They were as follows:

A. It was necessary to remove from the list the first element, which deals with the problematic situation. This element was not in actuality a characteristic of the generation component, but was in fact an essential precondition for its occurrence.

B. It was necessary to remove the second element, which is concerned with a voluntary abstention from conscious thought on a problem. A voluntary abstention describes another precondition or mind set for the mental acts of hypothesis generation. This element depicts a state of being of the investigator in which these acts occur, but does not characterize directly the nature of these acts.

C. With respect to the fifth element, which is concerned with the timeless quality of hypothesis generation, I removed the "variety of formats" aspect. The fact that hypotheses are formulated in a variety of formats again depicts a state of generative thinking in which the characteristics of this thinking occur.

D. It was necessary to consolidate two elements of the list. The fourth and sixth elements together referred basically to the same quality of hypothesis generation--that is its synthetic nature.

E. A separation of the list was necessary. The third element describes both the imaginary and metaphorical nature of the generation component. During my verification experiences, I found these to be discrete characteristics.

F. The final insight did not affect the specific characteristics of the list. It came about from my inability to apply the eighth element, which describes the suddenness quality of hypothesis generation, when working on the third and fourth chapters. I arrived at the understanding that the illumination stage is totally dependent upon

> incubatory experiences. Therefore, I felt it necessary to delineate the two stages which compose the generation component.
>
> My new list of explicit characteristics of the generation component incorporated five qualities of incubatory thought (synthetic, imaginative, intuitive, metaphorical, and timeless) and one quality of illuminatory thought (suddenness). Another verification period followed where I applied this new list successfully to the SCIS and Essence I programs. I could examine and evaluate each of these curricula to discover the extent to which each fostered the five characteristics of incubatory thought.

In retrospect, I have come to internalize the stages of the Wallas model into my own thinking. I am especially aware of the overlapping way in which these stages operate. In the above example of my inquiry process, I could not of course recall and describe all of the back and forth movements my thinking traveled during the course of my investigation. I am convinced, however, that I incubated on one aspect of my problem while I was in preparatory or verificatory stages of thinking about another aspect.

I now consider the final list of six characteristics of the generating component to be firm enough to warrant additional verification, in the form of further researches relevent to science teaching. These studies should be both theoretical and empirical in nature. Some examples of fertile research areas that I feel are pertinent to this study are discussed in the implications and recommendations section.

Implications and Recommendations

The Nature of Scientific Inquiry

This study suggests that the nature of scientific inquiry is inextricably connected to the teaching of science. In order to provide additional support for this connection, several research areas are recommended. Studies are needed which trace the effect of inductivism, hypothetico-deductivism, and other philosophies of science on the teaching of science. More specifically, a goal of these studies could be to determine the effect of various philosophical positions, concerning the nature of scientific inquiry, on the present overemphasis in science teaching on the hypothesis testing component.

One important source of evidence utilized in identifying the characteristics of the hypothesis generating component came from case-study reports of scientific investigations. This evidence was utilized inductively to derive these characteristics. Studies are needed which examine other case-study reports in a deductive manner for evidence of the six characteristics of the generation component.

In addition to case-study reports, the Wallas model of scientific inquiry provided a source of information. Studies are needed which examine other models of scientific inquiry to determine whether commonalities exist among the characteristics of these models.

Research in Science Education

This study suggests that the hypothesis generating component is a crucial process which should be encouraged in science teaching. Furthermore, it was suggested that this component has not received enough attention because of its private and subjective nature. Studies are needed which examine the nature of the research methodology of science education. A goal of these studies could be to legitimize the personal and subjective nature of the generation component as an important area of research. Another goal could be the development of observation and self-report instruments which measure the characteristics of the generation component.

This study suggests that the definition of scientific inquiry, as a two-component, complementary process, is a relatively recent conception. Furthermore, it is suggested that the total significance of this concept has not fully reached science educational settings. Studies are needed which provide a historical perspective for the profession of science education. A goal of these studies could be to determine the significance of various periods and events (such as the Committee of Ten in 1900, the NSF curriculum movement of the 1960's, and the research concerning the information processing strategies of each cerebral hemisphere) in relation to the present practices of science teaching.

Incubatory Thinking

This study suggests that the incubation stage of the

Wallas model is more important and manipulatable in science educational settings when compared to the illumination stage. Studies are needed which examine further the five characteristics of incubatory thought. One goal of these studies could be to determine whether all of these characteristics have to be encouraged to facilitate incubation, or whether only some of them need to be encouraged to create this facilitation.

Observational studies are needed in science educational settings at all levels to determine how much incubatory time is required to foster the hypothesis generating component. Also, studies are needed which determine if the occurrence of incubatory thought in students is a function of age, socioeconomic status, intelligence test scores, or scores on creativity measures.

Guided Imagery

This study suggests that guided imagery could foster incubatory thought in science teaching. Studies are needed in science classrooms which determine the effectiveness of this instructional strategy in facilitating hypothesis generation during scientific inquiries. A goal of these studies could be to determine the quality and quantity of generated hypotheses of students exposed to this method in comparison to a group that has had no incubatory instructional strategy. Another goal could be the comparison of the effectiveness of guided imagery in relation to other incubatory instructional strategies (such as deferred judgment and meditation).

In addition, studies are needed which determine the effectiveness of teachers and students in creating their own guided imagery experiences, which relate to science concepts under consideration. A goal of these studies could be to determine whether students can be taught to purposefully abstain from conscious thought on a problem (i.e., give themselves the "wise person" fantasy).

Science Teaching and Curriculum Development

This study suggests that the hypothesis generating component has been underemphasized in both science teaching and science curriculum development. Studies are needed which create, identify and/or examine instructional strategies which satisfy the characteristics of incubatory thought, and which are applicable to science teaching.

In addition, studies are needed which develop "methods and materials" courses in teacher training settings that provide both in-service and pre-service students with a two-component definition of scientific inquiry. More specifically, these courses could be built around a model of scientific inquiry (i.e., the Wallas model) in order to allow for a wholistic perspective of the process of scientific inquiry.

Studies are needed which examine the SCIS and Essence I programs in operation in science classrooms. A purpose of these studies could be to determine whether the differences in the goals of these programs with respect to the generation component are translated and applied in actual practice.

Also, studies are needed which examine other current science educational curricula to discover the extent to which they encourage incubatory thinking for each student. One goal of these studies could be the identification of specific points in a particular curriculum where an incubatory instructional strategy is appropriate, and could be inserted.

A Futuristic Perspective

Science education, at all levels, is becoming more aware of its right hemisphere. The obviousness of the left hemisphere is no longer an excuse for ignoring this seat for all incubatory thinking. What we can expect in the future of science teaching is a more balanced learning and curriculum model, which incorporates fully the characteristics of incubatory thought with the qualities inherent in the processes of induction and deduction.

An analogous model was visualized in the 19th Century by the poet William Blake. He pictured human growth and development as traveling through three stages. Beginning at birth, the person is in the stage of innocence. Events are right-hemispherically accepted as is, without rational analysis. As the person reaches adolescence, he/she leaves this phase and enters into the realm of experience. Accumulated events form logical, left-hemispheric patterns which lead to life goals. The final stage, higher innocence, represents a marriage, or synthesis, between the two earlier stages. The stages of innocence and experience form a complementary relationship so that events which are encountered by the person appear simultaneously as both unique entities and as entities which can be classified as similar to a set of previous experiences.

If we metaphorically connect the stages of Blake's model of human growth to the evolution of science education, it can be viewed that this profession is presently at the interphase between two stages--experience and higher innocence. Historically, the height of innocence for science education rested in the realm of the Nature Study curricula: a period where external reality was observed and accepted as it expressed itself to the student. The height of experience for science education came with the advent of the National Science Foundation curriculum projects, which were initiated around the time of the Sputnik launch in 1957. The heavy emphasis placed on the testing component is an important indicator for this period. The student was asked to perform operations unlike those requested in the Nature Study era. The major thrust during this period was on what the student could do with his/her observations of the external world.

At this present point of interphase, a synthesis or marriage between these two eras in the history of science education is occurring. The personal, intuitive observations of the student, in encountering the external world (emphasized in the Nature Study period), is becoming as essential as the objective, rational viewpoint, which concerns itself with operations based on these observations. It is a major intent of this study to facilitate this transition. It is hoped that by presenting the two complementary components of scientific inquiry in a perspective which celebrates each, this facilitation will occur.

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